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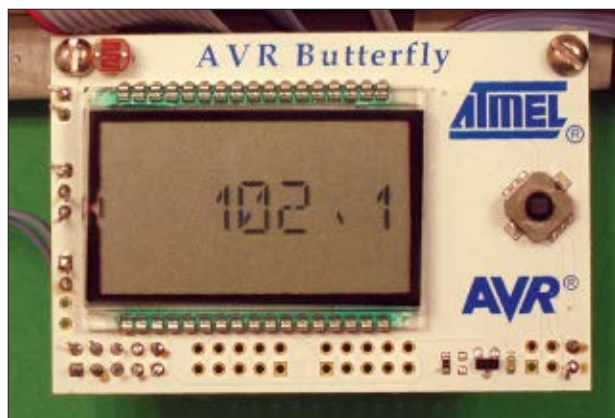
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Give yourself an advantage in the turns and on the straight-aways next time you're racing.

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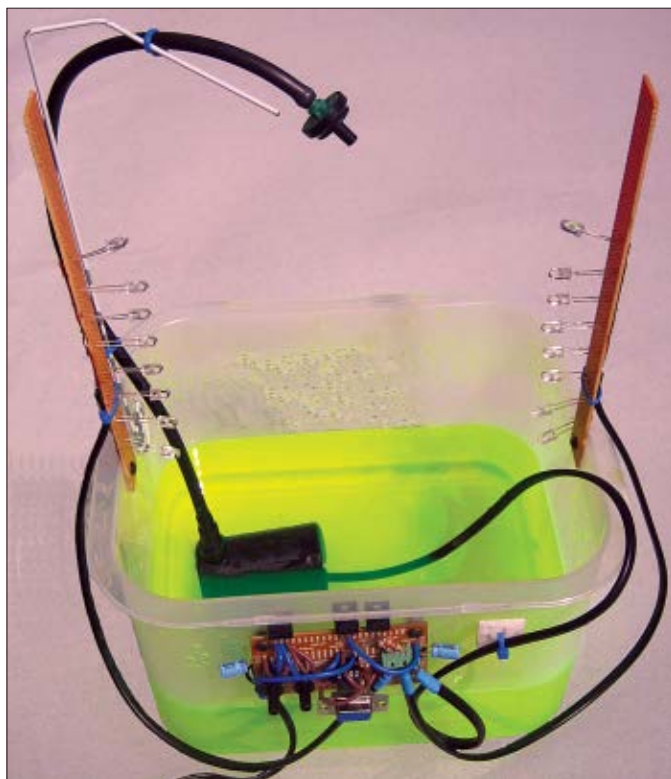
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Make water stand still with this tabletop fountain and learn a little about science in the process.

■ By Dan Danknick

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Be sure to check the Nuts & Volts website for downloads that go along with these projects.

Nuts & Volts (ISSN 1528-9885/CDN Pub Agree #40702530) is published monthly for \$24.95 per year by T & L Publications, Inc., 430 Princeland Court, Corona, CA 92879. PERIODICALS POSTAGE PAID AT CORONA, CA AND AT ADDITIONAL MAILING OFFICES. POSTMASTER: Send address changes to Nuts & Volts, P.O. Box 15277, North Hollywood, CA 91615 or Station A, P.O. Box 54, Windsor ON N9A 6J5; cpcreturns@nutsvolts.com.

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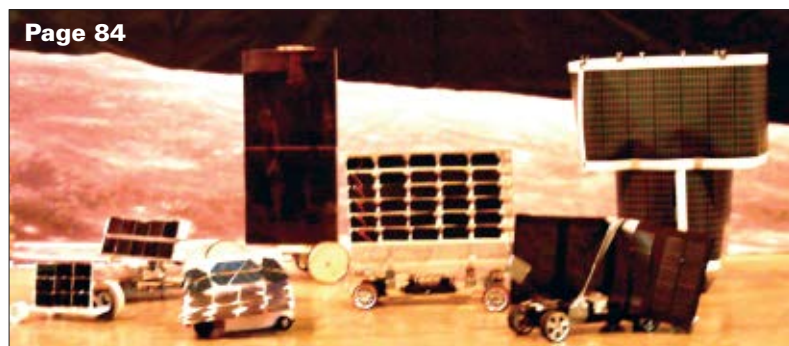
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"HOW TO" BASICS

Watch for articles with this banner that will cover the basics of electronics for newbies and be good refreshers for seasoned DIYers.



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by Bryan Bergeron, Editor

DEVELOPING PERSPECTIVES

Going Green with LEDs

Have you ever done the right thing for the wrong reason? When I explored the option of replacing the halogen bulb in my Electrix magnifying work lamp with LEDs, I was simply tired of singeing my knuckles when working on SMT components, and couldn't find a compact fluorescent to fit the bulb socket. I was also looking for an excuse to work with the new high-intensity LEDs on the market. Of course, the 'right reason' to make the move would have been increased efficiency and an associated reduction in greenhouse gases.

Figure 1 shows my work lamp before the LED modification. A 100W halogen bulb sits recessed in an aluminum reflector. Figure 2 shows the lamp after the LED mod, with four LEDs flush mounted on a 2 mm thick aluminum sheet.

Figure 3 shows the upgrade components — a 24 VAC output transformer, four high-power white LEDs, and a constant current supply. The LEDs are 05027-PW14, White High Current K2 Star LEDs, available from www.LEDSupply.com. The \$7.50 LEDs produce 100 lumens @ 1,000 mA at 3.85V, and a brilliant white 6,500K color temperature. The constant current supply is a 1,000 mA BuckPuck, also available from www.LEDSupply.com. Although both AC and DC supplies are available, I chose an AC model (03021-a-1-1000 - \$15) because I had an extra transformer in my parts box. The BuckPuck accepts 7-24 VAC input and produces a constant 1,000 mA output. An added feature of this model is a trimpot output adjustment for varying the light intensity.

Wiring the LEDs is simply a matter of stringing the LEDs in series and attaching the appropriate polarity of the constant current supply to the string. I stuffed the transformer and constant current supply in the head of the lamp, in the space that was previously occupied by the

indentation for the bulb in the aluminum reflector. The only downside to this arrangement is that the head is a bit heavier than before, and I have to tighten the tension on the supporting arm to keep it from drooping.

One of the challenges of maximizing the longevity of LEDs is avoiding high temperatures. For this reason, I elected to use a thermal epoxy (see Figure 4) to mount the LEDs instead of using hardware. Sold by LED Supply under the brand Arctic Silver Thermal Adhesive, the thermal epoxy (\$13) makes short work of mounting the LEDs. The epoxy has a five-minute working time, and you don't have to worry about drilling a dozen holes and possibly over-tightening a bolt and shattering an LED mount. With the thermal epoxy, the LEDs run warm to the touch, even after hours of operation.

Using my Sekonic light meter, I determined that the light output is only about a quarter of original output with the halogen bulb. However, the lamp provides more than adequate illumination. In addition, it's cool, the light is white, and I can work with the LEDs a millimeter from my hand in total comfort.

From a purely economic standpoint, the conversion was costly: \$32 for the LEDs, \$15 for the constant current supply, \$10 for the transformer, and a scrap piece of aluminum. However, the LEDs will outlast several of the \$25 halogen bulbs required by the original lamp design and consume significantly less energy. In addition, I now have a pure white light source that's perfect for close-up video and still camera work.

Several years ago, I made the move from incandescent bulbs to daylight compact fluorescents, primarily for the white light, and I haven't looked back. For many consumers interested in going green, LEDs, halogens bulbs, and compact fluorescent bulbs are becoming more popular as the price for these alternative light sources drops. Eventually, the move away from incandescents

will be mandatory. According to a congressional bill passed in December 2007, traditional incandescent light bulbs will begin to be phased out in 2012, with a complete ban finalized in 2014. Under the measure, all light bulbs must use 25% to 30% less energy than today's



FIGURE 1. Work lamp before LED mod.

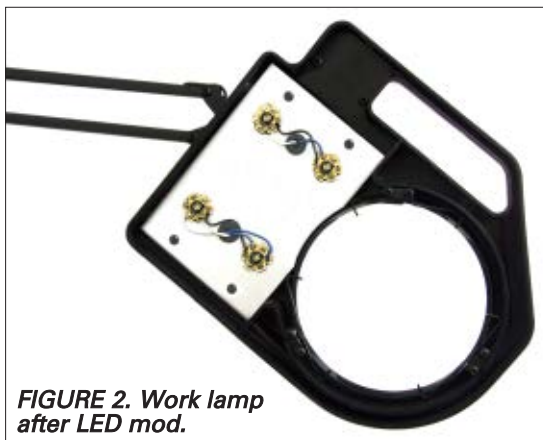


FIGURE 2. Work lamp after LED mod.

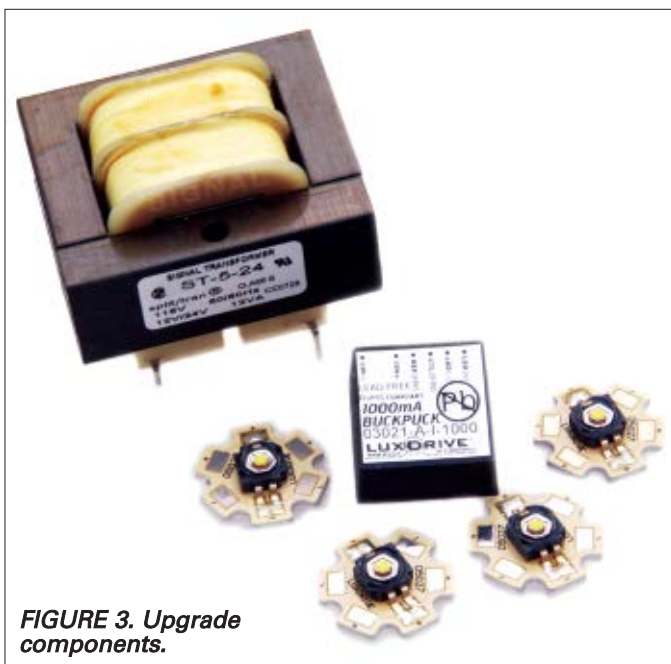


FIGURE 3. Upgrade components.

products by 2012 to 2014. The phase-in will start with 100-watt bulbs in January 2012 and end with 40-watt bulbs in January 2014. By 2020, bulbs must be 70% more efficient.

As illustrated by my lamp conversion project, the current limitation isn't LED efficiency or lifetime, but the initial investment. LEDs are not yet universally cost-effective replacements for incandescents and compact fluorescents. However, in certain niche areas, the added cost is acceptable. A highly publicized conversion involves replacing the 160, 100W mercury vapor lamps on the Brooklyn Bridge in NY with 24W LEDs. The LEDs are supposed to last three times longer than the lamps and save 24 tons of greenhouse gases per year.

What niche areas of alternative lighting can you identify and exploit — for your purposes and the good of the planet? If you devise something, please consider sharing it with your fellow readers. **NV**

RESOURCES:

Arctic Silver; Thermal epoxies and compounds; www.arcticsilver.com.

LED Supply; High-power LEDs and constant current drivers; www.ledsupply.com.



FIGURE 4. Thermal epoxy adhesive.



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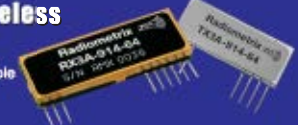
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WRITER SHEDS LIGHT ON RECENT ARTICLE

Ed: Following [bracketed italics] is Gerard Fonte's reply to Alex Dell's comment in the April issue. A full response from Gerard on other comments about his power supply article, along with a complete parts list is available on the Nuts & Volts website at www.nutsvolts.com.

Near the end of Mr. Fonte's article on "Basic Analog Power Supply Design" when he calculates turn-on surge current through the bridge rectifier diodes, well I think it's messed up. He calculates the inrush current as 42 amps and then goes on to say that the worst case is 21 amps because there are two diodes carrying the current. These two diodes when in conduction are in series not parallel; the current does not divide by two. Parallel diodes may not divide the current equally, anyway.

[The diodes are indeed in series. I

never stated or implied that they were in parallel. And the current is really reduced by a factor of two. Here's how. The only limit to the current flow out of the transformer is the forward voltage drop of the diodes. One diode has about 0.7 volts. If the transformer is shorted across one diode (for the positive half-cycle), the voltage at the transformer leads will be 0.7 volts – which is the same across the diode's leads – and a current of 42 amps will flow. If two diodes are connected in series across the transformer, then the voltage at the transformer's leads will be 1.4 volts (two diode drops). Since the effective resistance of the load circuit had doubled, the current flow will be halved (Ohm's Law), or 21 amps.

***Note:** A proper analysis of turn-on current surge is not trivial. The effective series resistance of the capacitor, the thickness of connecting wires, and a host of other factors affect the result. The original point of the exercise*

continued on page 32

Published Monthly By
T & L Publications, Inc.

430 Princeland Ct.
Corona, CA 92879-1300

(951) 371-8497

FAX **(951) 371-3052**

Webstore orders only **1-800-783-4624**

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Subscriptions

Toll Free **1-877-525-2539**

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P.O. Box 15277

North Hollywood, CA 91615

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■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

CLOCKS VIE FOR FIRST PLACE

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■ NIST physicist Till Rosenband adjusts the quantum clock.

At present, the US time standard is based on the NIST-F1, a cesium fountain clock developed at the National Institute of Standards and Technology (NIST, www.nist.gov) lab in Boulder, CO (so named because it uses a fountain-like movement of atoms to measure frequency and time interval). It constitutes our contribution to a group of international clocks that define Coordinated Universal Time (UTC) — the official world time. As of the summer of 2005, it was operating with an uncertainty of measurement of about 10^{-15} , which translates into accuracy of better than ± 1 s in 60 million years. But apparently the cesium atom's natural resonance frequency (9,192,631,770 Hz) isn't fast enough, so a number of alternative technologies are competing to become the next standard. These include devices based on a variety of atoms, including strontium, calcium, mercury, aluminum, and ytterbium. This level of accuracy

may seem of little practical importance, but the next-generation clocks can be useful in such things as network synchronization, satellite navigation, deep-space communications, and fundamental Earth studies.

Leading the horse race as of this writing is a "quantum logic clock" (so named because it is a spinoff of the lab's research on quantum computers) that is based on the natural vibrations of a single mercury atom. This one would stay accurate to within 1 s over 1 billion years. But the NIST recently performed some accuracy measurements (with precision to 17 digits) and discovered that a device

using an aluminum ion is only about 20 percent behind the mercury clock. "The aluminum clock is very accurate because it is insensitive to background magnetic and electric fields, and also to temperature," noted Till Rosenband, the NIST physicist who built the clock. "It has the lowest known sensitivity of any atomic clock to temperature, which is one of the most difficult uncertainties to calibrate."

Both clocks have plenty of room for refinement, so stay tuned to see

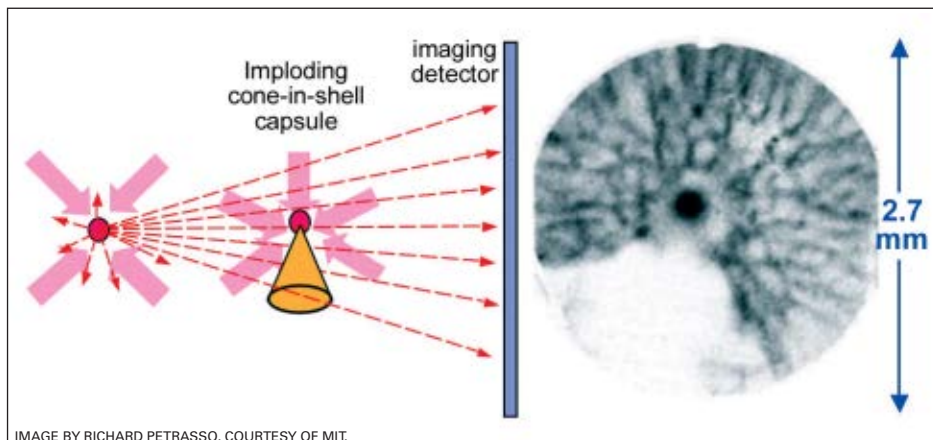
which eventually wins out. In the meantime, if you are a few trillionths of a second late for work, you still have an excuse.

SNAPSHOTS FROM THE REACTOR

With media and politicians focusing attention on wind power, fuel cells, and biofuels made from everything from corn to pond scum, nuclear fusion remains the stepchild of alternative energy. Nevertheless, advancements continue, and one of the latest comes from MIT (www.mit.edu) and the University of Rochester (www.rochester.edu).

Using a laser system at Rochester's Laboratory for Laser Energetics, a group of physicists has devised a process that produces "snapshots" of the high-energy, high-temperature reactions that are central to controlled reactions. Apparently, each reaction event ("ignition") must occur with nearly perfect symmetry for fusion to work, but there previously was no way to measure how symmetrical a reaction might be. We have already been able to detect the particles released by the

■ Diagram of the system used to study implosions of hydrogen fuel.



imploding gas, such as protons, x-rays, neutrons, and photons. But it is now possible to take a picture of the generated electric and magnetic fields.

The process (see diagram) requires two implosions: the one to be studied and another that illuminates the first. The first lasts about 3 ns, and the second can occur anytime within that period. A stream of protons are emitted by implosion no. 2, all carrying 15 million eV of energy. The protons are charged, so their paths are affected by fields surrounding implosion no. 1. The effect is recorded by an imaging detector, thus creating the snapshot.

In case you were wondering, such an implosion could produce from 10 to 150 MJ of energy, the latter being roughly equivalent to a gallon of gasoline. The National Ignition Facility, scheduled to open at the Lawrence Livermore National Lab in 2010, is targeting the 2010 to 2012 time frame to achieve the first controlled ignition. The next step will be figuring out how to put it into practical use for generating electricity.

COMPUTERS AND NETWORKING

NEW IBM MAINFRAME

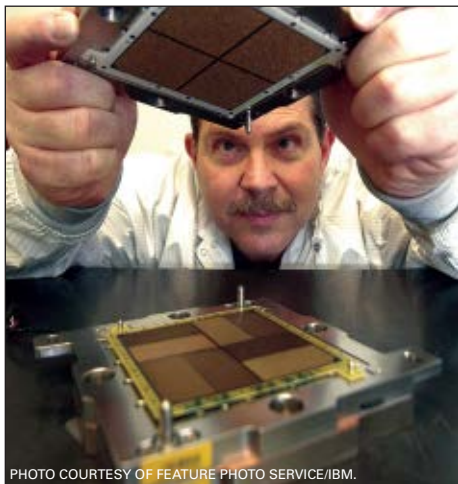


PHOTO COURTESY OF FEATURE PHOTO SERVICE/IBM.

■ Technician Len Centonze assembles a multi-chip module — the processing engine at the heart of the new z10 mainframe computer.

Most of the glory these days goes to hot new servers, desktops, and laptops, but there is still a market

out there for mainframes. One of the latest is IBM's model z10, the first upgrade to the z series in about three years. The z10 is specifically designed to handle the rapidly growing load of digital transactions on the Internet.

According to IBM (www.ibm.com), the new model offers the computing power of 1,500 x86-style servers while using 85 percent less juice and occupying 85 percent less floor space. Compared to its predecessor — the z9 — you get 50 percent higher speed and up to 100 percent better performance in CPU-intensive jobs. The 64-processor machine uses Quad-Core technology and is built to be shared, offering support for “hundreds to hundreds of million users.”

One of the available operating systems is z/OS, which can manage transactions based on preset policies, adjusting on the fly to peaks and valleys in demand. The z10 can save users a few bucks by consolidating x86 software licenses at up to a 30:1 ratio, and IBM says that clients with existing z9 leases can trade them in for new systems at a lower monthly rate. If you want to purchase one outright, rumor has it that the range of configurations runs from \$100,000 to \$1 million.

FREE CUSTOM RADIO

Sure, live radio streams from the Internet are nice but, as with broadcast radio, you are at the mercy of the source. Wouldn't it be great to find a radio station that plays only what you like? Well, try out Jango (www.jango.com). This free service allows you to create your own radio stations (apparently as many as you want) by entering a list of your favorite artists. It plays mostly tunes from your favorites but also generates recommendations and sends a few of those your direction. You can accept recommendations, trash them, or add them to your list of favorites. You can even rate individual songs to

regulate how often they come up.

There doesn't seem to be an official explanation of the site's name, but we might presume that it is a tribute to the late great Django Reinhardt, a Belgian Sinto Gypsy jazz guitarist whose recordings span the range of 1928 to 1953. Indeed, the system contains quite a few of Reinhardt's works.

Jango is in beta as of this writing, so its biggest shortcoming is a relative lack of material. It has never heard of Albert Collins and can pull up only one each for B.B. King (“The Thrill is Gone”) and Mose Allison (“The Seventh Son”). But if you go more mainstream, you'll probably do better. Jango also provides some possibilities for interacting with other users who share your musical tastes, but you'll have to explore that for yourself.

CIRCUITS AND DEVICES

BUILT-IN EMI/ESD PROTECTION FOR USB

USB 2.0 specs call for EMI and ESD protection, but this can be difficult to provide as component space becomes more limited and smaller chips become more susceptible. One solution is to incorporate filtering directly on the connector, which is what you get with the Spectrum Control (www.spectrumcontrol.com) line of USB connectors. These drop-in replacements for unfiltered connectors have a working voltage of 5 VDC, a maximum

■ Various connectors provide EMI/ESD protection in a standard USB package.



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INDUSTRY AND THE PROFESSION

ENGINEERS AND JIHAD

It is not news that a strangely high percentage of terrorists have engineering backgrounds. On June 30, 2007, Bilal Talal Samad Abdullah and Kafeel Ahmed drove a Jeep Cherokee into the main terminal of Glasgow International Airport and tried to blow up a load of propane canisters. Abdulla is a medical doctor and Ahmed (who died from burns suffered in the attack) was an Indian engineer. On July 14, Hicham Dokkali, a Moroccan engineer, tried to blow up a bus load of tourists in the city of Meknes. On August 4, two Egyptian men were arrested near a Navy base in South Carolina, and a load of pipe bombs were found in their car. Ahmed Abdellatif Sherif Mohamed is an engineering graduate and teaching assistant at

the University of South Florida, and Youssef Samir Megahed is an engineering student. The list goes on and on, and even Mohamed Atta (of 9-11 fame) was trained in architectural engineering. But the question is, what's going on here?

According to a highly controversial paper published by the University of Oxford (www.ox.ac.uk), engineers are more likely to be Islamic terrorists than any other profession. In the 90-page document, titled "Engineers of Jihad," sociologists Diego Gambetta and Steffen Hertog attempt to explain it. Surprisingly, they conclude that it has nothing to do with technical skills or social conditions, but a particular mindset. The authors conclude that engineers tend toward monism (there is only one true solution) and simplism (there is a simple, rational answer to everything), which makes them a particularly fertile ground for recruitment into radical groups. The report

is available at jkeckert.com/EofJ.pdf, if anyone wants to read it. It may be just pedantic claptrap but, just in case, be nice to the guy who repairs your TV set.

THE KING IS STOPPLED

Finally, we must sadly note that Microsoft Chairman Bill Gates, after 13 years at the top of Forbes' list of the world's richest people, has dropped to no. 3. Bill did increase his net worth by \$2 billion last year, up to \$58 billion, but Berkshire Hathaway's Warren Buffet picked up a cool \$10 billion for a net worth of \$62 billion. On target to take the top spot soon is Mexican telecommunications tycoon Carlos Slim Helú, who jumped from \$30 billion to \$60 billion in the last two years. Analysts attribute Gates' fall to Microsoft's offer to buy Yahoo for \$44.6 billion, which sent Microsoft stock prices spiraling downward. Well, better luck next year.

current rating of 1A, and a maximum contact resistance of 30 m. They meet the requirements of USB 2.0 and USB On-The-Go (OTG) specifications, and all are RoHS compliant. The USB 2.0 versions use an inductive filter, but you can also get the USB 1.1 version with a capacitive filter. Common applications cited by the company include test and measurement equipment, notebook computers and multimedia, industrial controls, and data acquisition. They will set you back about \$1 to \$3 each, depending on quantity.

MICRO FAN NOW THINNER

If your latest design needs a micro-size cooling fan, take a look at the Super-Flow Micro fan from Jaro Thermal. The company now offers a version that measures only 15 mm sq x 4 mm thick. It runs on only 2.5 VDC (making it useful for PDSs, cell phones, portable power supplies, and space-limited applications in general), yet it turns a snappy 26,000 rpm to move 0.3 cfm of air. The units are designed for >50,000 hrs of



PHOTO COURTESY OF JAROTHERMAL.

■ The Super-Flow Micro fan.

operating life and can withstand physical shocks of >700 G. Detailed specs are available at www.jarothermal.com/cat-DC-FAN-AD1502lx.htm.

ECO-FRIENDLY SPEAKERS

Last year, a company called Fashionation (www.fashionation.com) turned up at the Consumer Electronics Show, defining itself as a "group of trendy individuals whose chic taste and hip personality are united together

by the combination of hot style and the love of music." Translation: we sell glitzy iPod accessories.

A recent offering is the line of Eco-Speakers, which are tiny 3.25-in cubes that extract sound from your iPod or MP3 player. They fold flat for storage and portability and are powered by the USB connection. This, of course, is a mixed blessing; they require no amplifier or batteries, which simplifies things, but the sound quality is about what you would expect. However, they are made entirely from recycled materials, so maybe the crappy sound will be offset by the joy of being environmentally friendly. A pair lists for \$14.95. **NV**



■ Earth-friendly speakers use no batteries.

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STAMP APPLICATIONS

PUTTING THE SPOTLIGHT ON BASIC STAMP PROJECTS, HINTS & TIPS

■ BY JON WILLIAMS

MORE SURPLUS SUCCESS

I MAY HAVE MENTIONED MY FRIEND BRIAN once or twice. Brian's a great guy — a super smart IT professional by day and a bring-down-the house DJ by night. When I lived in Dallas, Brian was a tad jealous because I had Tanner (geek heaven) within minutes of my home. So, I move back to Los Angeles a couple years ago and no more Tanner for me (and I miss them). But, what do I have? That's right! All Electronics — another gate into geek heaven. Brian was beside himself; what luck I have with my proximity to fantastic suppliers. Both Tanner and All are great about stocking new products as well as a boatload of interesting surplus. One of the cooler products that All carries — and at a ridiculously low price — is the VEX Robotics Transmitter and Receiver Add-on kit; brand new and in the box. You just can't beat that.

Until you get home, that is, and find out that the receiver in the box is not capable of [directly] driving servos. What? You see, the little receiver box was, in fact, designed to be interfaced with the VEX controller, so it simply outputs a continuous stream of servo pulse width data. Figure 1 shows what the output looks like on a scope.

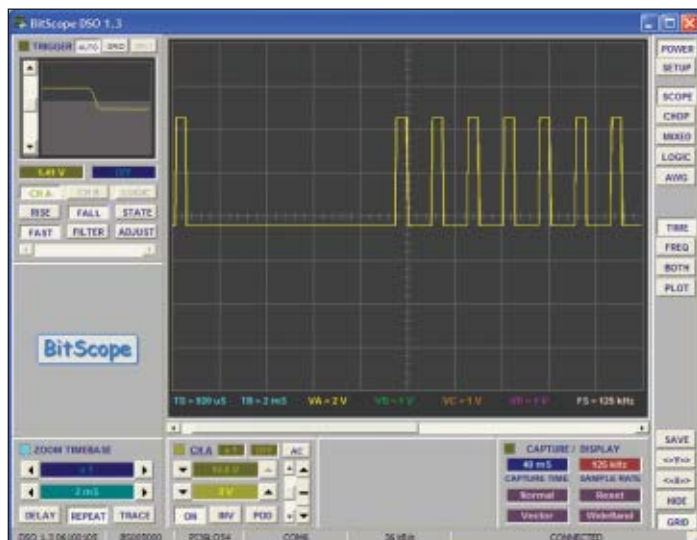
The pulses are active-low, and each is preceded by a framing pulse that is about 500 microseconds wide. Notice that one of the pulses is very wide relative to the others; nearly nine milliseconds. This is the sync pulse and

by finding this, we can get the position data to the correct servo. It turns out that using the PPM (pulse position modulation) is pretty easy. After locating the sync pulse, we simply wait for a high-going edge and turn on the first servo. We leave this output on until the signal has dropped and goes back high again; this is the signal to move to the next servo. This process continues for six channels.

The VEX transmitter has two joysticks that give complete analog control over channels one through four, and two push buttons each for channels five and six. With the last two channels, the servo pulse width will be 1.5 milliseconds (center) with neither button pressed. If the top button is pressed, the servo output drops to 1.0 milliseconds; if the bottom button is pressed, the servo output bumps up to 2.0 milliseconds. So while we can control servos with channels five and six, these channels are limited to three servo positions.

The circuit for converting the PPM stream to usable servo outputs couldn't be much simpler — and you can see this in Figure 2. This is a very generic SX circuit with a power supply, and connection for the receiver, and header for the servos. There are two jumpers on the board: one for selecting the servo power (+5V DC or Vin), and one for setting the behavior of servo outputs five and six.

■ FIGURE 1. VEX PPM Stream.



DECODING THE PPM STREAM

The first thing we need to do with the PPM stream is locate the sync pulse. I measured this to be about 8.9

milliseconds in duration. That said, all we have to do is wait for a low-going pulse that is longer than a servo position pulse; this will let us know we've found the sync pulse.

```
SUB WAIT_SYNC
  pulseTmr = 0
  DO WHILE PPM = 0
    PAUSEUS 10
    INC pulseTmr
  LOOP
  IF pulseTmr < 400 THEN WAIT_SYNC
ENDSUB
```

The subroutine called WAIT_SYNC takes care of this. The routine starts by clearing a timer variable (*pulseTmr*) and then dropping into a loop that monitors the PPM input for being low. As long as this input stays low, the timer will be incremented every 10 microseconds. Note that timing doesn't have to be super precise here; all we're looking for is a low pulse that couldn't be a position value.

When the PPM line goes high, loop terminates and the timer value is checked; if we find a pulse greater than about four milliseconds, we know that we have sync and we can return to the caller. If we happen to catch a

position pulse, the routine will run again.

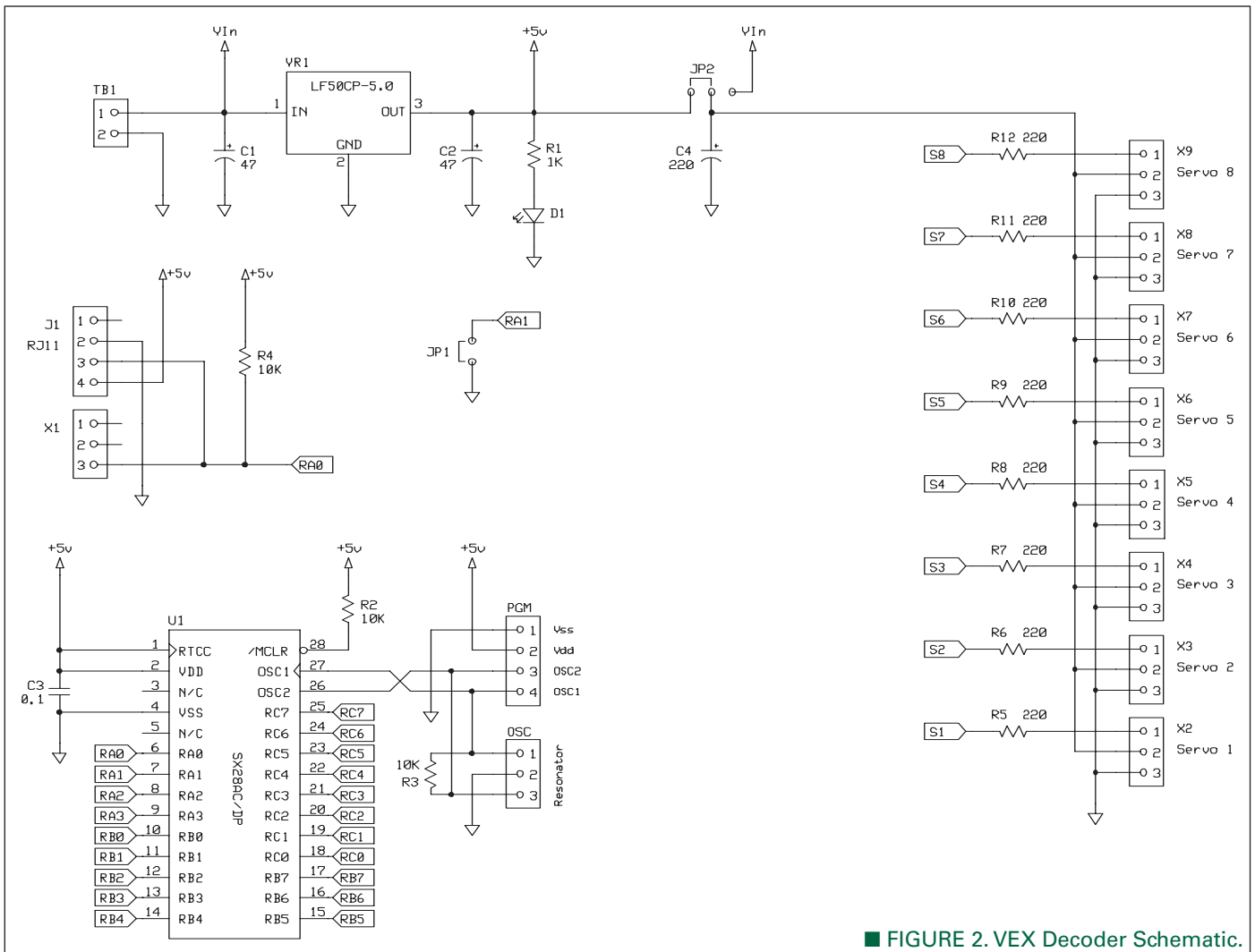
On start-up, we'll clear the servo outputs and then check the mode input jumper. As RA.1 has the internal pull-up enabled, we'll see a "1" on RA.1 when in standard servo mode, or a "0" when in what I'm calling "servo plus" mode. Let's look at standard mode first.

```
Start:
  SvoPort = %00000000

Main:
  IF MJumper = 0 THEN Servo_Plus
```

```
\ _____
\ Standard servo control
\ _____
```

```
Standard_Servos:
  WAIT_SYNC
  svoPntr = %0000_0001
  DO
    SvoPort = svoPntr
    WAIT_HI_LO
    WAIT_LO_HI
    svoPntr = svoPntr << 1
  LOOP UNTIL svoPntr = %0100_0000
  GOTO Start
```



■ FIGURE 2. VEX Decoder Schematic.



After waiting for the sync pulse, an internal servo pin pointer (*svoPntr*) is set to %00000001 to activate the first servo when applied to port RC. We drop into a loop where the pointer is written to the port, the program waits for the 500 microsecond framing pulse to end (high), and then waits on the timing pulse (low) to finish. To keep the listing neat, I wrote a couple dirt-simple subroutines for waiting on the edge transitions:

```
SUB WAIT_LO_HI
DO WHILE PPM = 0
LOOP
ENDSUB

SUB WAIT_HI_LO
DO WHILE PPM = 1
LOOP
ENDSUB
```

I deliberately made this program *no assembly required*, but if you're comfortable with assembly you could easily substitute an embedded instruction. Remember that SX/B allows the insertion of a single line of assembly code by prefacing the line with the backslash character. So, instead of WAIT_LO_HI, we could use:

```
\ JNB PPM, @$
```

And instead of WAIT_HI_LO we could use:

```
\ JB PPM, @$
```

The @\$ means to jump to the current address until the bit changes.

Back to the servo loop. After the framing and timing pulses are finished, the servo pointer is shifted left for the next servo. Once we have shifted this bit to Bit 6 of the variable, the loop terminates and the program jumps back to the top. Yes, the board has eight servo outputs (you'll see why in a bit) but their VEX transmitter only provides data for six. If you happen to find a device with a similar PPM output that handles eight channels, the code is easily modified.

SERVOS PLUS

I mentioned earlier that the VEX transmitter has two push buttons [each] for channels five and six – in standard servo mode, this limits the servo positions for channels five and six to the center and to either extreme (left and right). What if we had a robot or animatronic that required four or less servos and we wanted to use channels five and six as digital control outputs? How could we do this?

Handling the first four servos is similar to what we've just done. For channels five and six, we're going to measure the timing pulse. If that pulse is about 500 microseconds, it means the top button for the channel was pressed and we can turn the corresponding output on. If the pulse is about 1,500 microseconds, that means

the bottom button was pressed and we'll turn the corresponding output pin off. The only other possibility is that we measure about 1,000 microseconds; in this case, we will do nothing with the output.

```
\ _____
\ Four servos + two on/off
\ _____
\

Servo_Plus:
WAIT_SYNC
svoPntr = %0000_0001
DO
    SvoPort = SvoPort | svoPntr
    WAIT_HI_LO
    WAIT_LO_HI
    svoPntr = svoPntr << 1
    SvoPort = SvoPort & %0011_0000
LOOP UNTIL svoPntr = %0001_0000

Ctrl_Port1:
WAIT_HI_LO
pulseTmr = 0
DO WHILE PPM = 0
    PAUSEUS 10
    INC pulseTmr
LOOP

IF pulseTmr < 60 THEN
    Control1 = IsOn
ELSEIF pulseTmr > 110 THEN
    Control1 = IsOff
ENDIF

Ctrl_Port2:
WAIT_HI_LO
pulseTmr = 0
DO WHILE PPM = 0
    PAUSEUS 10
    INC pulseTmr
LOOP

IF pulseTmr < 60 THEN
    Control2 = IsOn
ELSEIF pulseTmr > 110 THEN
    Control2 = IsOff
ENDIF

GOTO Main
```

The servo portion of the loop starts out as before, but note now that instead of simply writing the value of *svoPntr* to the output port, we are ORing with the port. The reason we have to do this is to protect what is presently sitting on the output bits corresponding to channels five and six. Note, too, that there's one more line after the pointer is updated. This line clears the servo output that just ran while maintaining whatever happens to be sitting on channels five and six.

After completing the servos, the low-going timing pulses of channels five and six are measured and the output is updated as determined by the pulse. Pretty simple, really, and pretty darned useful.

So there we have it: a simple SX circuit that will turn

that \$30 VEX add-on kit into something that can actually drive servos and digital outputs. One last note before we move on. As the timing is controlled by the VEX transmitter, we can actually run this circuit using the internal 4 MHz clock source. If you do this, you can leave R3, the OSC socket, and the resonator off the board. I put them onto mine so I have options — you can see in the photo of the completed board (Figure 3) that R3 and the socket are installed, but the resonator is not.

DOUBLE IT UP

Having such a svelte circuit leaves us with a bit of a dilemma when using ExpressPCB's mini-board service: There's a ton of unused board space. Should we let this go to waste? Absolutely not! Let's double it up. When I started laying out the board, I found that the circuit would comfortably fit in half the space of a standard mini-board. Excellent — let's just copy-and-paste and get two boards for the price of one.

Not so fast, there, chief. Before we double-up any of your boards, we need to do a thorough check of the layout using a link to the schematic. This will save us a lot of trouble later; not all (as I found out), but most. Save the single board file separately so you can come back and update it if necessary.

I did, and here's why. While having lunch with my "networking" pal, Peter, he talked about making generic boards as generic as possible, and this really is the case with this board. It dawned on me — especially having just written a servo animation driver for the Prop-SX — that I could add another connector and make this board a standard servo controller.

If you look closely at the layout, you'll see that the RJ-11 sits on top of a three-pin header; this allows me to stuff the board two different ways based on what I want. The RJ-11 allows me to make the standard VEX decoder, or use phone cable for my input. If I want to create a standard servo controller for a BASIC Stamp or SX project, I'll replace the RJ-11 with a three-pin servo header.

Figure 4 shows a screenshot from ExpressPCB with the completed layout for one board. After this file is saved, it's a simple matter of copy, paste, and then adjust position (while everything is still highlighted) of the duplicate parts. Save the double board as a separate file. And note that once we've doubled things, using the "Highlight Net Connections" tool



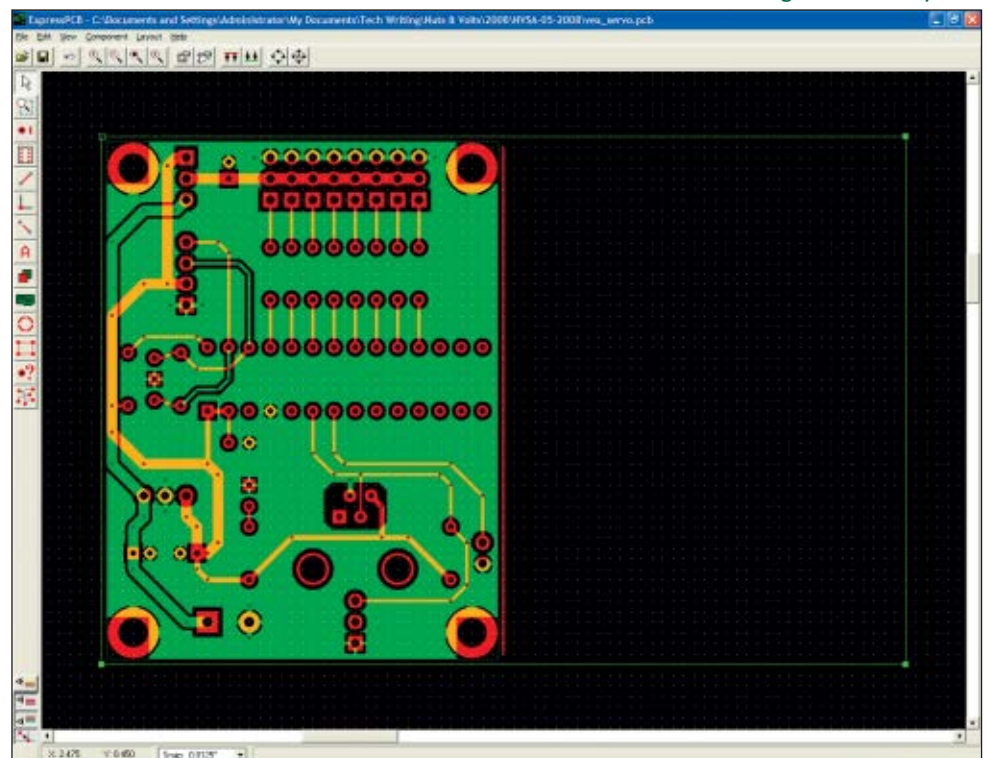
■ FIGURE 3. VEX Decoder Ready For Testing.

is no longer functional as we have duplicated part numbers.

Since we did a "background" servo driver last May I won't go into that, but what I will show you is how I created the servo animation driver I mentioned earlier. Many artists use a program called VSA (Visual Show Automation) for running props and servo-based animatronic displays. VSA allows one to integrate servo movement and sound very easily, and has become a favorite, especially with its low price (about \$50).

VSA uses the SEETRON (Scott Edwards) MiniSSC protocol as its default. Being a very clever guy, Scott made

■ FIGURE 4. Single Board Layout.



► PARTS LIST

Item	Description	Supplier/Part No.
► C1-C2	47 μ F	Mouser/647-UVR1V470MDD
► C3	0.1 μ F	Mouser/80-C315C104M5U
► C4	220 μ F	Mouser/647-UVR1C221MED
► D1	3 mm LED	Mouser/859-LTL-4222N
► J1	RJ11	Mouser/571-520250-2
► JP1-JP2	0.1" pin strip header	Mouser/517-6111TG
► Jumpers	0.1" shunt	Mouser/151-8000-E
► OSC*	0.1" pin socket	Mouser/506-510-AG90D
► PCB		ExpressPCB.com
► PGM	0.1" R/A header	Mouser/517-5111TG
► R1	1K	Mouser/299-1K-RC
► R2, R4	10K	Mouser/299-10K-RC
► R3*	10K	Mouser/299-10K-RC
► R5-R12	220 Ω	Mouser/299-220-RC
► Resonator*	4 MHz	Parallax/250-04050
► Resonator*	20 MHz	Parallax/250-02060
► Resonator*	50 MHz	Parallax/250-05060
► Socket	28 pin	Mouser/571-1-390-261-9
► TB1	Terminal block, 5 mm	Mouser/571-2828362
► U1	SX28	Parallax/SX28AC/DP
► VR1	LF50CP-5.0	Mouser/511-LF50CP
► X1-X9	0.1" pin strip header	Mouser/517-6111TG

* = Optional components

Note: JP1, JP2, and X1-X9 are cut from a single 40-pin part.

the protocol simple; to change the position of a servo, the host will send three bytes to the controller: sync, servo number, position. By using a virtual UART and servo driver, the foreground program for a MiniSSC-compatible servo controller becomes downright trivial:

```

Start:
  center servos
  PUT pos, 150, 150, 150, 150, 150, 150, 150,
  150

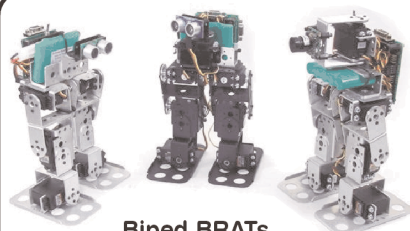
Main:
  sync = RX_BYTE
  IF sync <> 0xFF THEN Main

  chan = RX_BYTE
  value = RX_BYTE

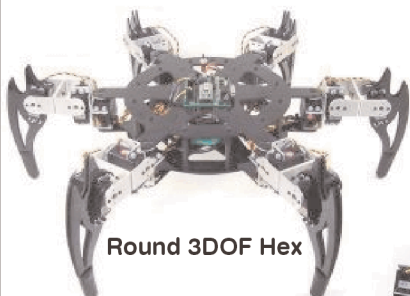
Process_Value:
  IF chan < 8 THEN
    value = value MIN LO_LIMIT
    value = value MAX HI_LIMIT
    pos(chan) = value
  ENDIF

  GOTO Main
  
```

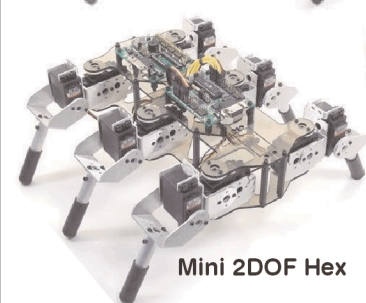
Yes, that's it. At Main, we monitor the input stream until a 0xFF shows up; the next two bytes are the servo number and position,



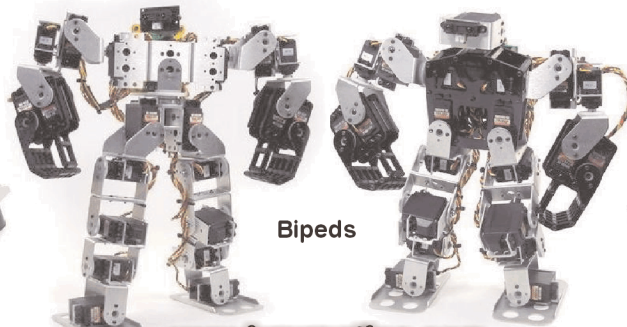
Biped BRATs



Round 3DOF Hex



Mini 2DOF Hex



Biped

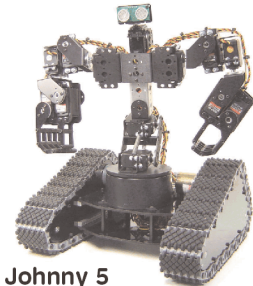
Lynxmotion

The Lynxmotion Servo Erector Set

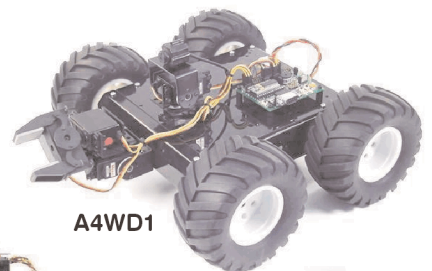
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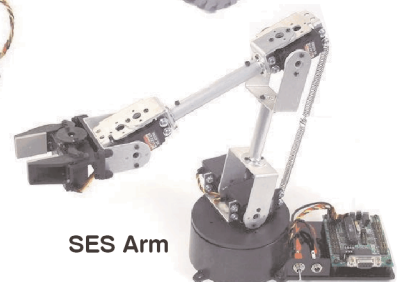
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respectively. If the servo number is valid, the position gets checked against hard position limits (to prevent servo damage) and written to the servo driver. My friends in the Dallas Personal Robotics Group have a saying: *It's harder than it looks*. In this case, however, it really isn't.

There's a great lesson here: We shouldn't be afraid to explore trails blazed by others to see if we might learn what they did. For example, why did Scott select 0xFF as the sync value? Because — with the position units used — that would never be a valid position value. I know that this seems terribly obvious, and yet I want to encourage you not to take the simple things for granted. Many of us do and that leads to unnecessary complications. Whenever possible, keep things simple. Simple is fun. Simple is elegant. Simple is [usually] robust.

Okay, it's your turn now. There is still a bit of space on the board — even the half board — and a useful exercise might be to add IDC-style headers so that you can access all of the RA and RB pins; this would make the board truly generic. It doesn't cost anything but time to experiment with ExpressPCB, so why not give it a try? Even if you don't build the servo board, what you learn will pay off in future projects.

Until next time — Happy Stamping, SX style! **NV**

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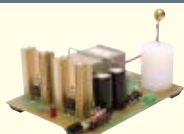


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TS1 Touch Switch Kit \$9.95

Voice Switch



Voice activated (VOX) provides a switched output when it hears a sound. Great for a hands free PTT switch, or to turn on a recorder or light! Runs on 6-12 VDC and drives a 100 mA load.

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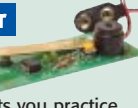
DTMF Tone Decoder



Decodes DTMF Touch Tones from telephones, radios, etc. 200mA output drives relays, LEDs, digital devices, and more. Decodes 0-9, *, #, A, B, C, D. Runs on 5VDC

TT7 DTMF Decoder Kit \$24.95

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CPO3 Code Practice Oscillator Kit \$9.95

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MK125 Light Activated Switch Kit \$8.95

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MK108 Water Sensor Alarm Kit \$7.95

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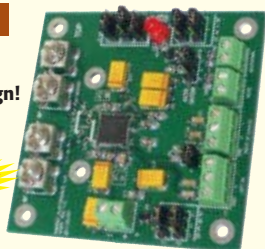
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New For 2008



40 Watts, 87% Efficient, No Heat, All On A 2 1/2" Board!

The UAM4 is the big brother to the extremely popular UAM2. It uses the latest spread spectrum amplifier technology to bring you clear, crisp, high-power audio without any of the heat which is normally associated with such an amplifier. It's extremely clean Class D design produces two independent 20 watt outputs! This can also be bridged to an extremely efficient (87%) single channel (mono) 40 watt amplifier.

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The high impedance input is designed to use your choice of either a balanced line input or an unbalanced signal source using easy to connect Euro terminal blocks. Logic connections to ground are also provided to mute and/or shut down the amplifier. You can also enable the built-in over temperature signal to activate one of these controls automatically! Easy to use board jumpers offer selectable gain of +22dB, +25dB, +29.5dB or +36dB to match your input levels. Board jumpers also enable protection and shutdown options as well as stereo/mono/bridge mode. The amplifier also features built-in click and pop suppression to protect not only your ears and sanity, but your speakers and equipment!

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- ✓ True Laser protects over 500 yards!
- ✓ Audible & visual alert!
- ✓ 5A external trigger relay

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LTS1 Laser Trip Sensor Kit \$29.95

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- ✓ Regulated power supply!
- ✓ Temp controlled soldering station!
- ✓ RoHS lead-free compatible!

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Next up, the regulated lab DC power supply. Switch selectable ranges of 3V, 4.5V, 6V, 7.5V, 9V, and 12V provide a continuous duty current of 1.5 amps with a 2 amp peak! Features both overload protection and overload indication.

To the right we have a high quality temperature regulated soldering station. The 24V low voltage iron features an isolated ceramic 48 watt temperature controlled element. Front panel control gives you variable tip temperature control from 150°C to 450°C and LED indication of power-on and heating-on. Runs on 120VAC.

LAB1U 3-in-1 Multifunction Lab \$119.95



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- ✓ Today's technology with yesterday's display!
- ✓ Custom hand-made wooden base!
- ✓ The ultimate conversation piece!



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IN14TM Retro Nixie Clock Kit, Teak Maple Base \$329.95
IN14TMWT Retro Nixie Clock, Teak Maple Base, Assembled \$369.95

Passive Aircraft Airband Receiver

- ✓ Monitors the entire 118-136 MHz aircraft band without tuning!
- ✓ Great for air shows!
- ✓ Passive design, can be used onboard aircraft!
- ✓ Patented circuit and design!



For decades we have been known for our novel and creative product designs. Well, check this one out! An aircraft receiver that receives all nearby traffic without any tuning. It gets better... there is no local oscillator so it doesn't produce, and can't produce, any interference associated with all other receivers with an LO. That means you can use it onboard aircraft as a passive device! And what will you hear? The closest and strongest traffic, mainly, the one you're sitting in! How unique is this? We have a patent on it, and that says it all!

This broadband radio monitors transmissions over the entire aircraft band of 118-136 MHz. The way it works is simple. Strongest man wins! The strongest signal within the pass band of the radio will be heard. Receiver sensitivity is less than 2uV for detectable audio. Headset cord is coupled as the antenna giving you great reception. Also includes a set of stereo ear buds. Runs on a standard 9V battery. Available thru-hole kit or SMT factory assembled & tested.

ABM1 Passive Aircraft Airband Receiver Kit \$89.95
ABM1WT Factory Assembled & Tested ABM1, SMT Version \$159.95

OBDII CarChip Pro

- ✓ Stores up to 300 hours of trip details!
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- ✓ Records extreme acceleration and braking!
- ✓ Automatic accident log, records the last 20 seconds before impact!
- ✓ View and reset engine diagnostic trouble codes!
- ✓ Test for preliminary emissions status!



New For 2008

With the CarChip Pro from Davis Instruments, you'll have complete access to all your vehicles diagnostic data at your fingertips! Sort miles by type, business or personal miles, set thresholds for alarms, calculate gas mileage, log extreme acceleration and braking, speed, engine parameters, and a whole lot more! No more taking your car in to see why your "check engine" light is on. The CarChip Pro will automatically provide the trouble codes and allow you to reset it!

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Q&A

WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:

- ✓ HD Radio
- ✓ Power Supply Filter Caps
- ✓ Tool Setter Modification

■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:

Q&A@nutsvolts.com

DC MOTOR PARAMETERS

Q I need your help on how to know or estimate the DC motor parameters if I haven't got the datasheet for the motor.

Mohammed S. Salah

A There are five basic motor types that I know about: shunt wound, series wound, compound series-shunt, permanent magnet, and brushless DC. Without taking the motor apart to see how it is wired, you can make some determination by measuring the speed-torque curve.

There is an IEEE paper: "A method for torque-speed curve determination for a DC compound motor without loading the motor" by Zhaohui Zeng and E. Rechie. The paper costs

money so I didn't read it, but it no doubt would be of interest to you.

The shunt wound motor may have two or four terminals. Four terminals will allow you to control the motor speed and torque by varying the field current. More current yields lower speed and higher torque. The motor is capable of high torque over a wide range of speed (see Figure 1).

The series wound motor only has two terminals and the only control is the applied voltage. The motor has high torque at low speed and can overspeed if not loaded. Automotive starter motors and most traction motors are series type.

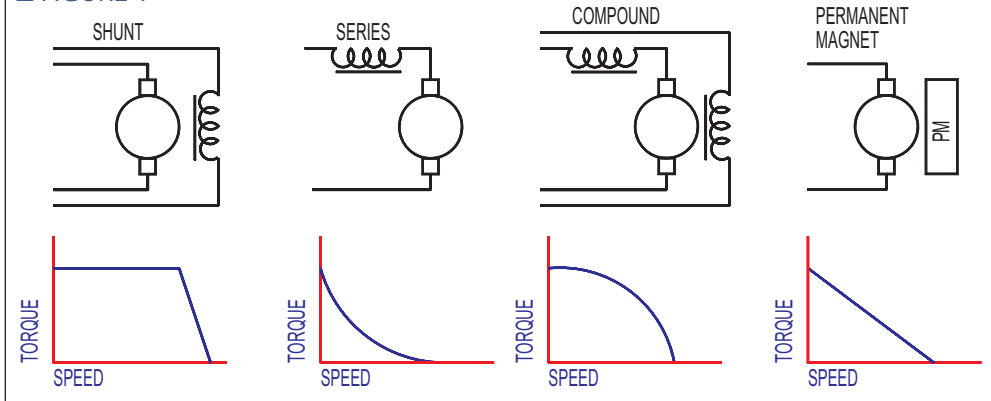
The compound motor combines the high starting torque of the series motor with the high torque at high speed, characteristic of the shunt motor. The speed-torque curve will depend on the amount of series winding. The curve shown in Figure 1 is typical.

The permanent magnet motor has a wound armature with brushes

but the field is provided by permanent magnets. This is similar to a shunt motor with constant field current; the available torque will linearly decrease as the speed increases. The brushless DC motor is a permanent magnet motor and has the same speed-torque curve. It is not shown separately in Figure 1.

In order to estimate the horsepower of a motor, you need to know the current rating. You can measure the diameter of the wire to the armature and look up the current rating in a handbook. The power input (P_{in}) is V_{in} times I_{in} and the horsepower input is $P_{in}/746$. The horsepower increases with voltage, and the limiting factors are how fast the motor can spin without damage and heat dissipation of I^2R losses. A rule of thumb is 1/2 watt dissipation per square inch of motor surface.

■ FIGURE 1



FREQUENCY DIVIDER

Q I'm looking for a circuit to divide 40 MHz by seven (down to 5.714 MHz) with a 4:3 mark-to-space ratio output. Can you help me with such?

Douglas Baker

A A fast counter is needed for 40 MHz; I chose the 74F161A, a synchronous four bit presetable binary counter (see

■ FIGURE 2

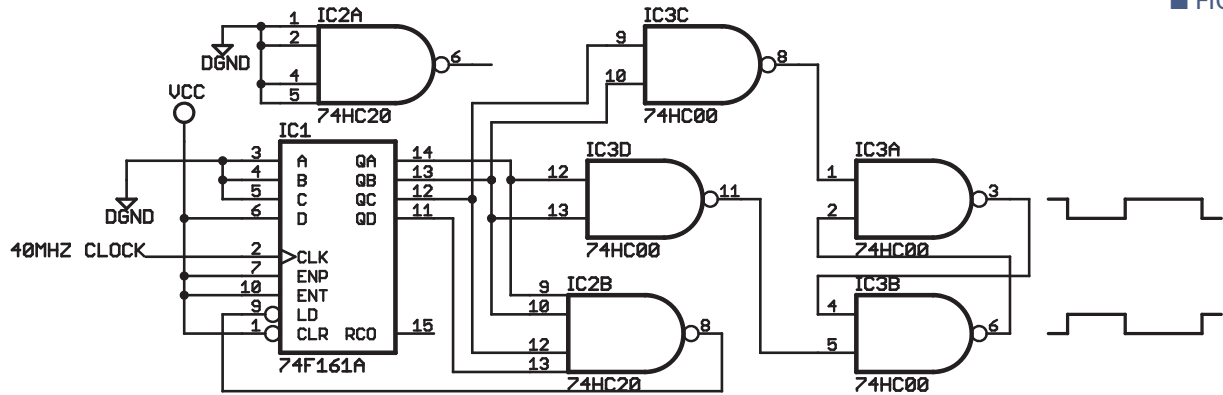


Figure 2). I could have decoded seven and fed back to the clear pin but everyone does that, so I did it different: The counter counts to 15 (1111) and loads 8 (1000) into the counter, then starts counting from there. At power up, the output does not have the 4:3 ratio until the count passes 11. The output is from a set-reset flip-flop composed of IC3A and IC3B. When the count is 11 (1011), IC3B is set until the count is 14 (1110) when IC3A is set. IC3A remains set until the count gets back to 11 (four clock pulses). Note that 15 and 8 are the same clock pulse.

TOOL SETTER MODIFICATION

Q I want to modify my Tool Setter that I am using on my milling machine. A tool setter is an instrument that is used for measuring the distance between the tip of an end mill and the top of the mill table. The circuit consists of a watch battery and LED. One side of the battery connects to the metal base of the tool setter which sits on the surface of the mill table. The other side of the battery connects to an LED. The other side of the LED connects to a metal plate on top of the tool setter that is insulated from the base. When an end mill is lowered and touches the top plate of the tool setter, the metal frame of the milling machine completes the circuit and turns on the LED. This now tells you that the end mill is exactly two inches above the surface of the milling machine table.

I want to modify this by adding a

set of contacts that will close when the LED comes on. This switch will be connected to the control program of the milling machine to indicate that the end mill is two inches above the mill table. The switched circuit of the mill is low voltage (5 VDC); there is also 12 VDC available if needed.

I am interested in your thoughts on a modification that would do this job.

Bill Blackburn

A A solid-state relay would be an easy modification. Just connect the LED input of the relay in series with the indicator LED as in Figure 3. The voltage drop of the LEDs is a little more than one volt so the battery voltage should be three volts minimum with 100 ohms in series, or you could use the 5 VDC with 330 ohms in series. The HSR312 is a solid-state relay in a six pin DIP package; Mouser part number 512-HSR312. You can mount it on perfboard; perhaps it would fit in the tool setter.

DUAL VOLTAGE BATTERY CHARGER

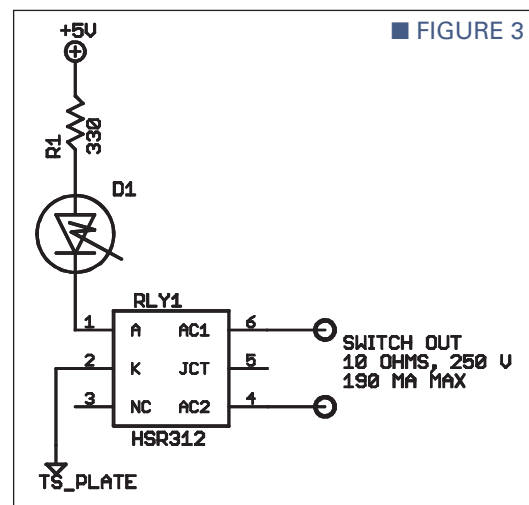
Q I am looking for two circuits: one for recharging NiCd batteries, the other for sealed lead acid batteries. I have a Ryobi drill with a 9.6V NiCd and charger that is very basic; just one resistor and a diode. I do not believe this is good for battery longevity. I also own two lanterns that have six volt sealed

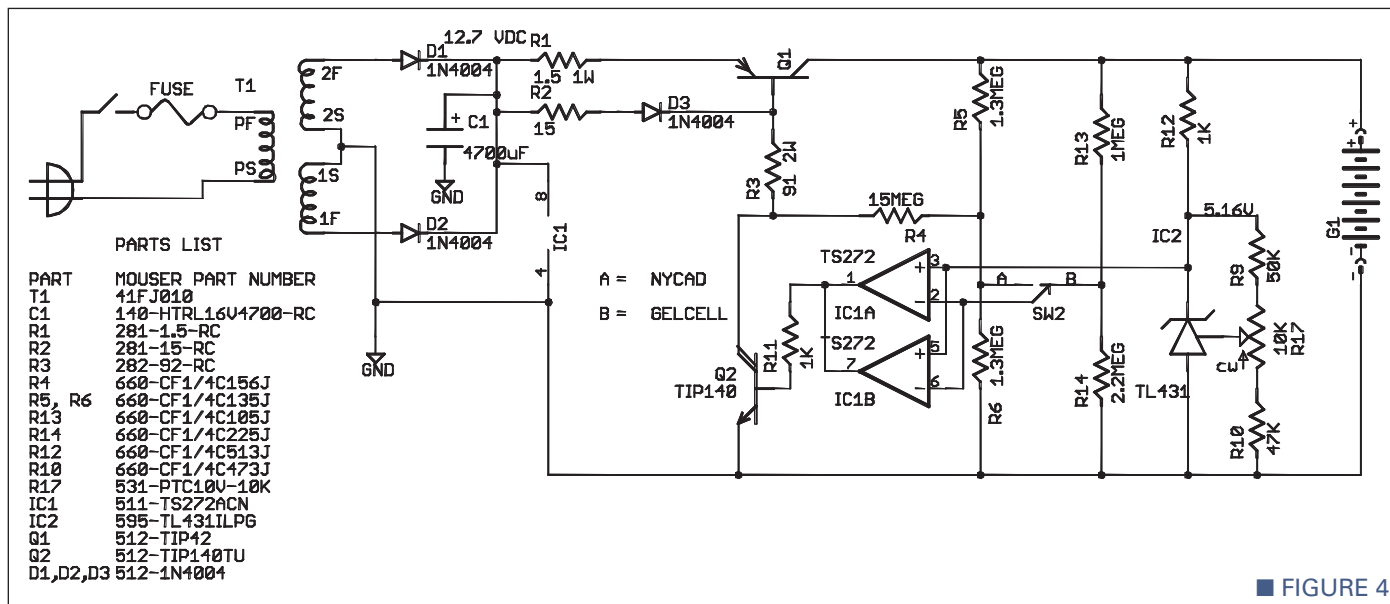
lead acid batteries and use the same charging system. I will be grateful for any information you can provide.

Ken Bartone

A I designed a circuit that will charge both batteries; there is a switch (SW2) that selects NiCd or gel cell. The charge current is low so the power dissipation in the pass transistor is not excessive, but the heatsink should be capable of at least three watts. Figure 4 is the schematic and the parts list is included. It is not necessary to filter the current to the battery, so C1 could be omitted, but the charging will go faster with it. The 18 VAC CT transformer will produce 12.6 VDC $[(18/2) * 1.4]$. The components R1, R2, D3, and R3 provide a current limit. When Q2 is turned on, the current through R2 and R3 (neglecting the base current of Q1) is $12/106 = 113$ mA and the voltage dropped across R2 is $113 * 15 = 1.7$ volts. This same voltage

■ FIGURE 3





MAILBAG

Dear Russell,

In response to "X10 Problem" in the March '08 issue, the effect that Mr. Mode is experiencing is not caused by a defective X10 appliance module. It is caused by the way the module was designed. Keep in mind this is an appliance module. There are challenges when trying to use it to control a compact fluorescent lamp.

These modules have a feature called local control. It provides a convenient way of turning on the appliance without using the remote control. Let's say you have a radio connected to the module. You are standing at the radio and want to turn it on but you don't have a remote control. All you have to do is shut the radio off with the radio's power switch and turn it back on. The module will sense that the load went away and came back and will turn on the power to the load.

CFLs confuse the module. They draw too little current when they are off. Sometimes when you use an appliance module to turn off a CFL, the module will turn right back on again. Also, part of the load sensing circuitry has a series resistor and parallel capacitor. This creates an old familiar circuit: the neon relaxation oscillator. When the module is off, the capacitor

charges through the resistor. When the voltage gets high enough, the lamp turns on, quickly discharges the capacitor, and the lamp goes off. The cycle repeats. That's why you will see the CFL flash periodically when it is turned off.

There is a fairly well known jumper inside the module that you can cut to disable load sensing. This will prevent the module from responding to changes in the load but it will not disable the relaxation oscillator problem. There is another modification for this.

To make both modifications (this is for the newer style AM466 module) do the following: To open the module, there is one screw between the power plug prongs. Be careful you don't lose the house and unit code dials; they will fall out as you pry the case apart. With the circuit board oriented component side up, with the power plug prongs on the top and the load receptacle jack on the bottom, locate and cut the jumper. It is located to the right of IC pin 9 just below and to the right of the right (wider) power plug prong. It is the only jumper on the board. Next, locate and cut the diode in the lower left corner of the board. It is below the relay. It is the only diode in that location next to a resistor and a capacitor.

That's it. Now the appliance module will to a very fine job of

controlling CFLs. No blinking, but no local control.

Rick Swenton

Response: Thanks for the feedback, Rick. As you can see, I know zip about X10. Many readers will be glad to get this information along with Mr. Mode.

Dear Russell,

In regards to the circuit to protect a GPS UNIT in the March '08 issue, there could be another reason. The GPS processor doesn't reset because of the way the ignition switch operates.

During the start phase, the accessories are turned off. This on-off-on sequence occurring during a few seconds and poor reset circuitry in the GPS can cause problems.

Mr. Bukowski might need a power-on delay module that has a short reset time. These are difficult to design. The timing element must be discharged when initially started, and off when it times out and when the voltage drops suddenly.

Ron Dozier

Response: Mr. Bukowski was using the cigarette lighter socket for power — which I assume is on all the time, — but your comment raises the possibility that using the accessory line from the ignition switch might solve his problem.

has to be dropped across R1, so the emitter current of Q1 is $1.7/2.7 = 0.63$ amps. The TL431 is a shunt voltage regulator providing a constant 5.16 volts DC reference to the TS272 op-amp positive input. The TS272 is a dual and I paralleled the inputs and outputs to give more drive to Q2. The NiCd battery voltage is divided by R5 and R6 to be slightly lower than 5.16 when the battery is discharged. The negative input to IC1 being low, the output is high, turning on Q2 and charging the battery. When the divided battery voltage exceeds 5.16V, the output of IC1 goes low, turning off the charging current and turning on D5 (a green LED), indicating that the charge is complete. At the same time, the positive feedback through R4 lifts the positive input higher so the battery has to discharge some before the charger is turned on again. The gel cell circuit is the same, just a different voltage divider.

WIND BATTERY CHARGER

Q My son is planning to build a wind generator for his senior project. The generator will be used to charge a 12V deep-cycle storage battery. The plans we have state the system can generate 84 watts at 12 volts in a 30 mph wind. We plan to use a charge controller to keep from overcharging the battery. There are several available on the Internet but thought it would be more fulfilling to build our own. Can you suggest a circuit to handle our needs?

Dave Pollatta

A A wind generator should always be loaded, otherwise it could over-speed in a high wind; therefore, I have designed a shunt voltage regulator for your charging system. The circuit shown in Figure 5 consists of a TL431 shunt regulator and power P-MOSFET. The TL431 has an internal reference of 2.5 volts. When the divided voltage at the input exceeds 2.5 volts, the output pulls down, turning on the MOSFET and shunting the excess current to ground. Since the drain is grounded, you won't need an insulator on the heatsink. The heatsink should have a rating of 0.6°C

per watt or better. Mouser part number 567-392-180AB is rated 0.43°C per watt and should be good but costs \$143, so you might want to make your own from a large aluminum plate. It would be neat to make a copper heatsink attached to the cold water inlet to the hot water heater so the heat dissipated by the MOSFET can preheat the water. The power MOSFET has a rating of 30 volts and 75 amps but it can't handle that much current in this circuit because the power rating (if you keep the tab at 25°C) is 180 watts, derated at 1.25 watts per degree Celsius. When you mount the transistor, use some heatsink compound to aid heat transfer.

The diode isolates the battery from the regulator so it will not discharge the battery when there is no wind. The diode is in a stud mount package (DO-5) and should be on the heatsink with an insulator; Mouser part number is 844-70HF60. There is a pot to adjust the regulated voltage over a small range. It should be set for 14.4 VDC to compensate for the diode drop of .6 volts.

POWER SUPPLY FILTER CAPS

Q I need a word of reassurance from you! I recently needed a power supply — 10 amps at 24 volts. When I went to my local distributor to get the filter caps, I was expecting soda can-sized monsters. What they had were 4,700 µF in a can that was 1" tall by approx. 1.5"

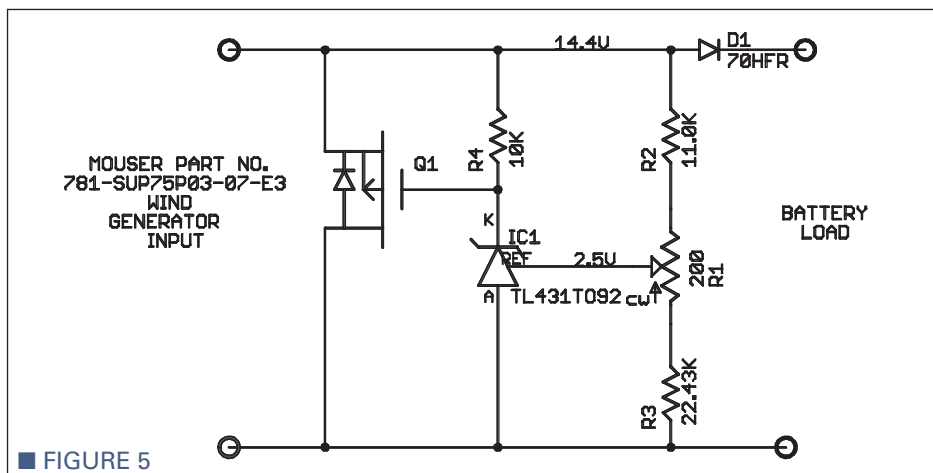
in diameter. Has technology improved that much or should I be concerned? Any word would be appreciated.

Geff Waite

A Well, technology has advanced, but one of those 4,700 µF caps is rated at about three amps ripple current, so you will need to parallel several. I simulated a 10 amp, 24 volt supply using five 4,700 µF caps in parallel. The source was 28 volts; the output was 24 volts with two volts of ripple at 10 amps load. The peak ripple current was 60 amps, which divided by five gives 12 amps peak per cap. I estimate the average to be under three amps for each cap so that should work.

HD AND DIGITAL TV

Q I'm really enjoying your articles on improved digital HDTV reception and would like to get down to the meat of optimizing my hilltop antennas. I have two Channel Master eight bay bowtie antennas each with mast mounted amps that feed separately to the TV and to the DVR. I do this to maintain the signal gain from each antenna and to minimize ghosting and other signal reflectance trouble caused by combining antennas on one feed. As we all know in the old days of analog TV, reflectance was a common problem but truthfully I'm not sure if this is a problem for digital broadcast. Would you please comment on this and recommend a method for measuring and optimizing a signal feed in





relation to multiple antenna feeds. Also, did you know that you can get a better HDTV signal off a good antenna that you can get from a cable company?

Robert Cataldo

A You can use a 1 GHz signal splitter in reverse to combine the two antennas and there will be no problem with ghosting, even with analog TV. Digital TV compensates for ghosts so

there is none, unless it is so bad that you get no picture at all. The video bandwidth for high definition digital TV (HDTV) is 37 MHz, but the broadcast signal is compressed to fit in the allotted 6 MHz channel; in fact, two HDTV signals will fit in one analog channel. There are two HDTV standards in common use: 720p and 1080i. The number is the amount of lines in the picture; the letter denotes p for progressive scan and i for

interlaced scan. The interlace scan does all the odd lines in 1/60th of a second, then does all the even lines in 1/60th of a second. Therefore, it has a refresh rate of 30 frames per second. The progressive scan does all the lines in 1/60th of a second and therefore requires twice as much bandwidth as interlaced. But, since the progressive scan is using half as many lines, the bandwidth for 720p is the same as for 1080i.

Since HDTV takes less bandwidth than analog TV, I don't see any reason that the wider bandwidth of the antenna would be any advantage over cable.

HD RADIO

Q I was reading the question Bryan Fischer asked about HD radio. My question is: Is there an HD radio kit on the market and who sells it? If not, who vends the HD radios? What is the cost? What are the advantages of HD over regular FM or AM radio?

Paul Kozlowski

A HD radio is a registered trade name; it does not stand for High Definition radio. HD radio is Hybrid Digital radio and its main advantage is that more channels can be put in the allowed bandwidth than is possible with analog FM or AM. There are presently over 1,200 hybrid digital FM stations on the air, but as far as I know the programming is not different from the analog signal. I did not find anyone advertising hybrid digital receivers for the 88 to 108 MHz FM band, although I found one Sony table radio in two stores. There is no quality of sound advantage in hybrid digital; analog FM stations already transmit more bandwidth than most people can hear and with low distortion. If it comes to pass that stations start transmitting multiple channels (classical, oldies, country, talk, data) and it is something the public wants, receivers may become available. I noticed that my son's newer car radio displays the song title and artist name; that probably is a digital channel within the analog or digital FM channel. **NV**

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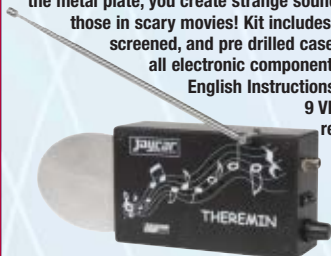
Audio Project Kits

Theremin Synthesiser Kit

KC-5295 \$34.95 + postage & packing

The Theremin is a weird musical instrument that was invented early last century but is still used today. The Beach Boys' classic hit "Good Vibrations" featured a Theremin. By moving your hand between the antennae and the metal plate, you create strange sound effects like those in scary movies! Kit includes a machined, silk screened, and pre drilled case, circuit board, all electronic components, and clear English Instructions.

9 VDC wall adapter required



"The Champ" Audio Amplifier

KC-5152 \$3.75 + postage & packing

This tiny module uses the LM386 audio IC, and will deliver 0.5W into 8 ohms from a 9 volt supply making it ideal for all those basic audio projects. It features variable gain, will happily run from 4-12VDC and is smaller than a 9 volt battery, allowing it to fit into the tightest of spaces.

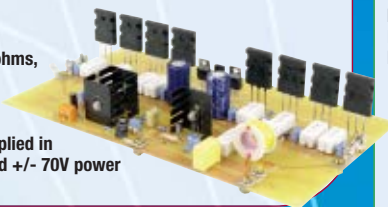
• PCB and all electronic components included.



Studio 350 High Power Amplifier Kit

KC-5372 \$119.95 + postage & packing

The Studio 350 power amplifier will deliver a whopping 350WRMS into 4 ohms, or 200WRMS into 8 ohms. Using eight 250V 200W plastic power transistors, it is super quiet, with a signal to noise ratio of -125dB(A) at full 8 ohm power. Harmonic distortion is just 0.002%, and frequency response is almost flat (less than -1dB) between 15Hz and 60kHz! Kit supplied in short form with PCB and electronic components. Kit requires heatsink and +/- 70V power supply (a suitable supply is described in the instructions)



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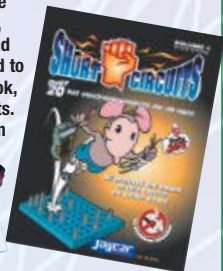


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NATIVE MODE ZX MICROCONTROLLER RELEASED

Elba Corporation is now shipping the latest member of its powerful multi-tasking ZX microcontroller

family intended for use by scientists, engineers, experimenters, and hobbyists. The new ZX-24n is a 24-pin "stamp format" device that offers performance enhancements and additional programming features compared to the company's ZX-24 and ZX-24a microcontrollers. All ZX-series microcontrollers are programmed in ZBasic, a subset of Microsoft's Visual Basic (VB6) with microcontroller-specific extensions and other productivity enhancements.

The ZX-24n is the first in a planned series of devices that operate in "native" mode, meaning that the user's ZBasic program is compiled to native machine code for the underlying microcontroller, in this case, the Atmel ATmega644P MCU. This is in contrast to the previously released ZX family members that use the "virtual machine" model (also known as the interpreter model). The new ZX-24n is largely source code compatible with the previously released ZX family members. The single unit pricing of the ZX-24n is \$59.95. Volume pricing is available.

The ZBasic programming language is a subset of Microsoft's Visual Basic (VB6) language with extensions suitable for microcontroller programming. The ZBasic compiler can detect common programming defects such as use of a variable before its initialization and other likely errors. The compiler incorporates advanced optimization techniques that help programmers pack more functionality into the available code and data spaces by, for example, eliminating unused or superfluous variables and unreachable code.

Programs for the ZX-24n may be edited, compiled, and downloaded

using a state-of-the-art Integrated Development Environment. The ZBasic IDE provides productivity-enhancing features such as word completion, call tips, auto-indenting, syntax highlighting, and undo/redo.

For more information, contact:
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USB ANALOG INPUT MODULES

ACCES I/O Products, Inc., released a new series of low cost USB analog input modules — the USB-AI Series. This high-speed USB-AI16-16A USB 2.0, 16-bit multi-function analog input board is ideal for precision measurement, analysis, monitoring, and control in many embedded applications. The USB-AI16-16A can sample inputs at speeds up to 500 kHz for the board's 16 single-ended or eight differential analog input channels. Standard features in the USB-AI Series include 16 digital I/O lines and a 16-bit counter/timer — all packaged in a small, rugged, industrial enclosure. With an excellent price/performance value, this family of boards also includes models with slower A/D speeds and a group of 12-bit modules for less demanding applications.

The USB-AI Series includes five models with list prices ranging from only \$339 to \$639. The boards feature eight standard analog voltage input ranges, two factory current input ranges (4-20 mA or 10-50 mA), and includes a data sample buffer and hardware real-time calibration capability. A unique channel-by-channel programmable gain feature

enables measurement of an assortment of large and small signals in one scan — all under software control at up to 500 kHz. The board's data buffer and ability to trigger the A/D in real time assures synchronized sampling that is unaffected by other computer operations — an essential requirement for signal, vibration, and transient analysis where high data rates must be sustained for short periods of time. Available accessories include a wide variety of cables and screw terminal boards for quick and easy connectivity.



Key features of the USB-AI Series include a high-speed USB 2.0 device with up to 500 kHz sampling rate; all functions fully software configurable; 16-bit and 12-bit models with 16 single-ended or eight differential inputs; eight input ranges, unipolar or bipolar; autocalibration and real-time hardware calibration, and oversampling for accurate data; unique channel-by-channel programmable gain feature; data buffer for A/D; synchronous, asynchronous, and timed trigger modes; 16 high-current digital I/O lines; 16-bit counter/timer for event counting or frequency generation; USB/104 form-factor for OEM embedded applications; small (4" x 4" x 1.25") rugged industrial enclosure; OEM (board only) option features PC/104 module size and mounting compatibility; extended temperature and DIN rail mounting provisions; all required power drawn from USB port, no external power adapter required.

The USB-AI16-16A is supported for use in most operating systems and includes a free Linux (including Mac OS X) and Windows 95/98/Me/NT/2000/XP/2003 compatible software package. This package contains sample programs and source code in Visual Basic, Delphi, C++ Builder, and Visual C++ for Windows. Also incorporated is a graphical setup program in Windows. Third-party support includes a Windows standard DLL interface usable from most popular application programs, and includes example LabVIEW VIs. Embedded OS support includes Windows XPe.

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READER FEEDBACK

continued from page 10

was to show that surprisingly huge currents are present. This is something that I thought was important to identify.]

Also, I don't agree with an LED on the primary side. If you do the math, you would need about a two-watt resistor to support this design. If you do need an LED on the primary side (I would put it on the secondary side after the bridge rectifier), I would do it this way: Put the 1N4004 in parallel but reversed (anode to cathode and cathode to anode) which would actually protect the LED from exceeding its PIV; replace the 10K with something much lower (you need a little resistance) and put a capacitor about 0.1 to 0.33 μF or so in series with the resistor (let the capacitive reactance limit the current and minimize the waste heat).

[Actually, there is an error on page 73 when I said 10,000 ohms gives 12 mA. It should have said 5,000 ohms because only the positive half-cycle passes through the diodes. This reduces the voltage to 60 volts RMS. The 5,000 ohm resistor would then dissipate 0.72 watts, so a two-watt resistor would still be appropriate.

Note: Using the capacitive reactance to reduce the AC line voltage is a very dangerous practice. If the capacitor shorts out, then the full AC potential is applied to the rest of the circuit. In this particular case, it's just an LED that will be destroyed. This is one of those "clever" tricks that get people into very serious trouble. Powering a project in this way leads to fires, severe electrical shock, and ruined test equipment. I have never seen any reputable commercial product use this approach, even though it saves money on a transformer. (That says a lot!) I will never suggest or endorse a design that uses this strategy for AC line operation.

This approach is not good for the LED, anyway. There will be a large turn-on surge through the capacitor that will travel through the LED. This will lead to early LED failure.

LEDs are not lamps. There is no need to run them at their maximum rated current. Lowering the drive

current by 50% reduces their apparent brightness by very little, but increases their lifetime by a factor of ten. The low-brightness LEDs (about 10 mcd) still provide very reasonable light levels with 2-5 mA of drive. But why use them? Jameco has a 2,000 mcd LED for \$0.21. These can certainly be driven at 1-2 mA or even less with a lifetime measured in centuries.

The final design in Part 2 uses a 30K resistor in the AC primary for 2 mA of drive. This resistor must dissipate 0.12 watts of power so a quarter watt device is adequate. The final design also specifies a 10K resistor for the DC side. This provides about 3.7 mA of current and dissipates about 0.14 watts of power, so a quarter watt part is adequate here, as well. In fact, the values were deliberately chosen for about an eighth watt of power so that a quarter watt part could be used with a good safety margin. The fundamental reason for the primary-side pilot light is for safety. Knowing when a piece of test equipment has AC power applied to it is important.]

Lastly, I think a 1N4004 diode in series with an LED is a poor PIV protection scheme. You are counting on the 1N4004 having no reverse leakage current or just low enough to not damage the LED. All diodes have some leakage; relying on it not to leak for the protection of the LED (which has a low PIV) is not a good design. If you need primary side indication, use the neon.

Alex Dell

[See the discussion in my reply to Mr. Stiles on reverse leakage.]

Gerard Fonte

ENJOYED ARTICLE — NO FOOLIN'!

Thanks for the great article in April's Personal Robotics column! When the digiencabulator goes into production, please let me know. I will connect it to my flux capacitor that Doc Brown promised to send to me and email the results to you. The time frame is April 1, 2009 or thereabouts. Thanks again for the info.

Gary Gugino



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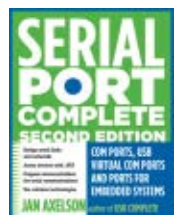
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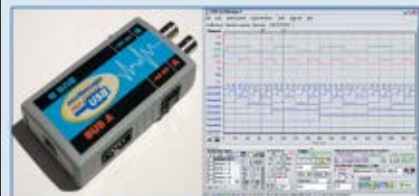
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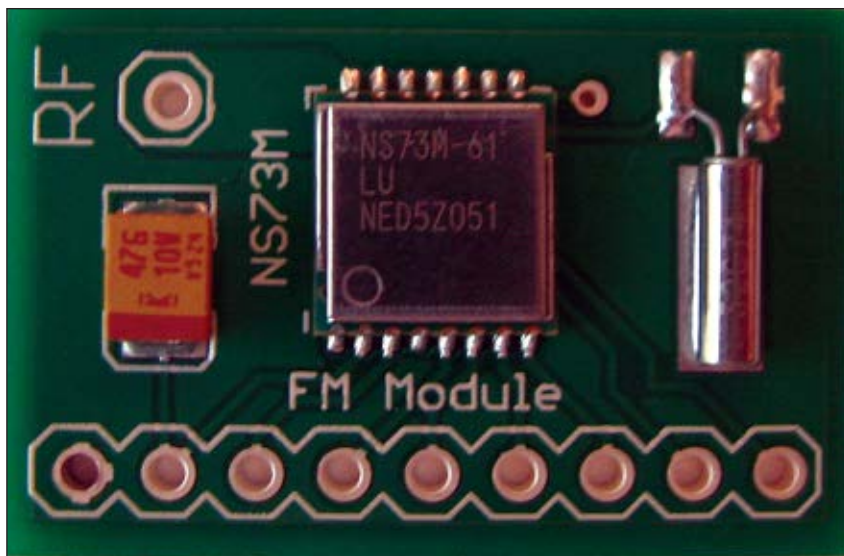
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BUTTERFLY

BROADCASTER

BY JAY CARTER

MP3 players are great when you are wearing earphones, but wouldn't it be nice to listen through your home or car sound system? Now you can! Just plug your player into this project and it will broadcast the music to any nearby FM radio.



The key component to this project is a thumbnail-sized FM radio transmitter on a chip — the NS73M — by the Niigata Seimitsu company. Just add a microcontroller and you can be on the air. No coils, no tricky alignment procedures, just pure digital bliss. Photo 1 shows the transmitter chip pre-installed on a small, experimenter friendly circuit board. This module is perfect for breadboarding. While many “wireless microphone” designs exist, low cost units often use a simple RF oscillator. The transmission frequency may be hard to set, and the units tend to drift off frequency easily. With the NS73M transmitter chip, the frequency is digitally selected with a microcontroller. The frequency is rock solid, being controlled by a crystal and a phase locked loop (PLL). Drifting frequencies are a problem of the past.

AVR Butterfly ATmega169 Processor

The ATMEL AVR Butterfly microcontroller board (shown in Photo 2) is perfect for this project. It includes an ATmega169 processor, six-character LCD display, five-position joystick, and a piezo-electric beeper, all put to good use in this project. The entire package is the size of a credit card, and costs about \$21. Its built-in RS-232 serial port is used for programming, while its 4 MB DataFlash and thermistor go unused in this application.

You will use the joystick to select the frequency to transmit on, which is displayed on the LCD. This makes

■ **PHOTO 1** (shown above). The FM radio transmitter on a chip, the NS73M, pre-assembled on a SparkFun Electronics breakout board.

frequency selection trivial. The processor stores the frequency in its internal EEPROM, recalling it when the device is turned on in the future. For repeated use, just turn the device on and hit a pre-selected memory button on the radio. It can't get any easier than that!

Although the Butterfly board includes a three volt coin cell battery for normal operation, it is best to use an external battery or power supply. The battery will run down quickly if the transmitter is used extensively on its 2 mW RF output mode.

I²C Communications

Connecting the transmitter module to the Butterfly board is simple as both run on three volts and no level converts are required. The transmitter can communicate using either a two wire I²C protocol, or a three wire protocol. I chose the I²C interface, and tied the transmitter's clock and data lines to those on the Butterfly's USI port, with additional 4.7K pull-up resistors on each line. The transmitter's latch pin is tied to ground, while the “IIC” mode pin is tied to three volts. A short wire is attached to the antenna terminal. Power and audio round out the connections. The transmitter is designed for

a maximum input signal amplitude of 200 mV RMS. For this reason, an attenuator with AC signal coupling is provided on the audio inputs to the transmitter.

The transmitter has a TEB terminal which is not tied to a Butterfly digital input in this configuration. It can be used to monitor the ability of the transmitter's phase lock loop to lock in on the desired transmit frequency using the currently selected transmitter "band." The transmitter has four possible bands used to cover the FM radio band from 87.5 to 108 MHz. In this configuration, the optimal band is selected based upon the frequency in use.

The NS73M transmits in stereo. It incorporates both pre-emphasis and a pilot tone without any additional external circuitry. The amplitude of the input signal required to give 100% modulation is software selectable, ranging from 100 mV RMS to 200 mV RMS. Typically, you'd just plug a patch cable from the MP3 player into the stereo audio input jack on the transmitter.

Basic Software

The software for the ATmega169 processor was written in Bascom-AVR Basic. As this dialect of Basic is designed for this family of processors, incorporates commands for I²C communications, EEPROM access, and floating point math, all of the tools are present to bring this project together easily. You can focus your attention fully on understanding the datasheet for the transmitter software control, and not on language and hardware barriers to its implementation. Neither the transmitter chip's manufacturer's nor the reseller's websites, nor Goggle turned up any pre-existing software for interfacing with the chip in I²C mode, or for implementing a user tunable interface. With no working examples to expand upon, close scrutiny of the datasheets and a little trial and error were in order. Before long, the transmitter was live with audio blaring from my nearby radio receiver.

The Basic code for this project is available on-line, and can be easily ported to other languages. Having a fully functional version to review will certainly pave the way for those wishing to follow. A pre-compiled hex file is also provided for those who do not have Bascom-AVR available to them.

The transmission frequency is determined by a 14 bit value uniquely determined for each frequency of interest. It is used in setting the transmitter's phase lock loop. Floating point math is a must for these calculations. Internally, the transmitter chip divides the FM radio band into four overlapping sub-bands, which require two additional bits when programming it. This data is dispersed across three of the 13, eight-bit registers in the NS73M. The Butterfly board has a 4 MBit DataFlash memory chip in addition to the 512 byte EEPROM within the processor itself. One could certainly calculate the frequency and band data for each frequency and store them in memory, recalling them as needed whenever the user selected a new frequency to transmit on. However, the floating point math instructions available — coupled with the speed of

the processor — make it easy to calculate the values on-the-fly. No look-up tables were required.

In designing the software, I chose to use an index pointing into the FM radio frequency band as the key parameter. The FM band is divided into 206 steps, each 0.1 MHz, stepping upwards from a base frequency of 87.5 MHz. This pointer is a small integer, easily stored in a single byte. Each press of the joystick simply bumps this pointer up or down by one, with roll-over to wrap the frequency around at both the high and low ends of the FM band. The processor uses this pointer to calculate the actual frequency to be displayed on the LCD (1 = 87.5, 2 = 87.6, ... 206 = 108.0). The frequency is then plugged into the PLL setup equations to calculate the 14 bit value which generates that frequency.

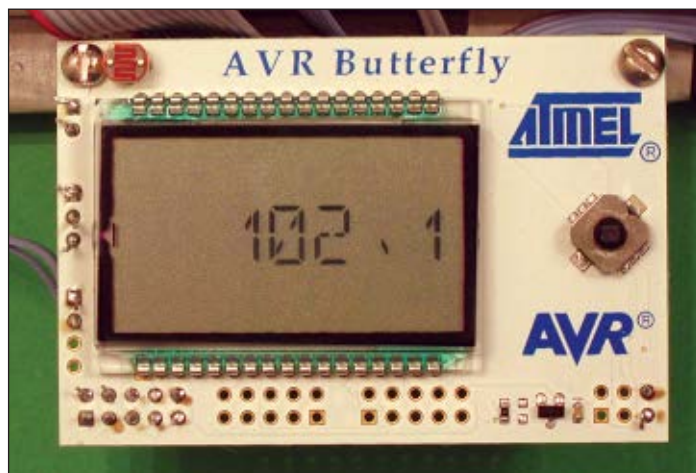
It is desirable to have the unit power-up on the same frequency it was last using. This is much more convenient than retuning the transmitter to a quiet spot on an FM radio each time it is used. By storing the frequency pointer, only a single byte of EEPROM memory is required for this purpose. The pointer method also saves you from storing over 600 bytes of look-up table information, had data tables been utilized.

The transmitter's datasheets elude to using the TEB signal to measuring the ability of the transmitter's PLL to lock in on the chosen frequency. If the PLL is having difficulty locking in and cannot obtain a stable transmission frequency, one bumps the internal, sub-band selection up or down until lock is obtained. I instead chose to measure the frequency range over which the PLL could obtain a lock while programmed for each of the four sub-bands. The program selects the optimal sub-band from this information and loads the correct sub-band selection whenever a new frequency is selected by the user.

Wireless Microphone

This project was designed with an MP3 player in

■ **PHOTO 2.** The AVR Butterfly demonstration and evaluation board, incorporating an ATmega129 processor, LCD, joystick, DataFlash memory chip, piezo-electric beeper, and coin battery.



mind. However, one could easily substitute a microphone and op-amp for the player, creating a wireless microphone. The small size, digital tuning, and crystal-controlled transmitting stability make this chip transmitter a natural for this purpose.

Audio Signal Generator

As small as it is, the Butterfly's processor is overkill for this application. With all that extra processing power available, I chose to add a simplistic audio signal generator to aid in testing the transmitter. Although one could use the D-to-A converter or PWM to generate a signal, I chose to generate a square wave by toggling a spare output bit high and low at a 1 kHz rate. A simple RC filter removed many of the high frequency components, essentially turning the square wave into an attenuated triangular wave. This signal was then fed into the audio input ports on the transmitter. Having a stable audio signal facilitated testing the rest of the project. Being able to create the signal from within the project itself was both fortuitous and convenient.

It is desirable to turn the audio signal generator on

and off as needed. When on, a small amount of the 1 KHz signal can leak into the transmitter even when it is disconnected from the audio inputs. It should be off, therefore, when the unit is connected to a real audio source. Pushing the joystick inwards usually stores the new frequency in memory for later use. However, if the frequency is set to 108 MHz (the top of the FM radio band), the unit toggles the audio signal generator on and off when the joystick is pressed inwards.

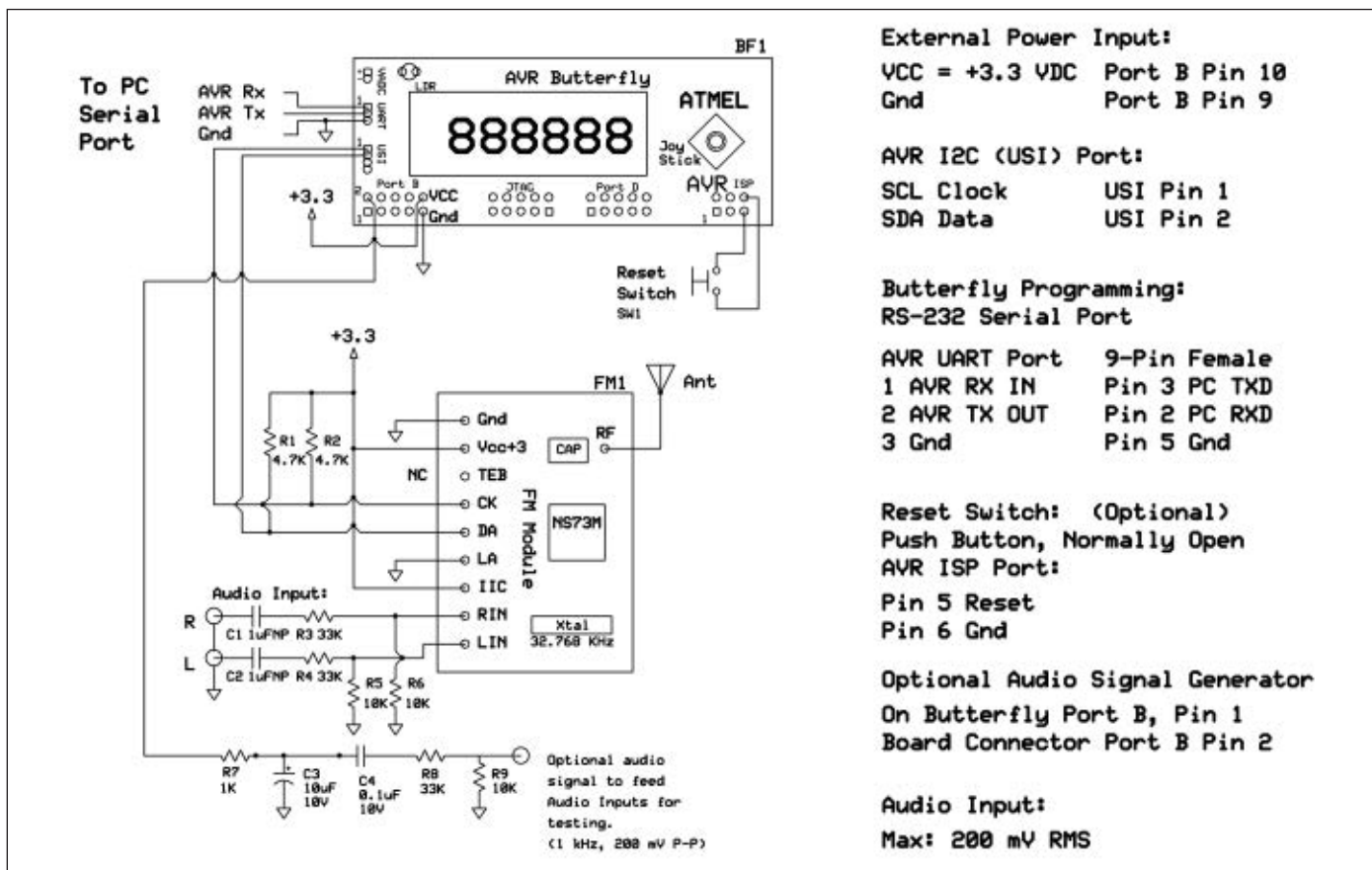
Construction Concepts

Figure 1 is the schematic for the project. Given the small number of components involved, one can lay this circuit out on a breadboard in a matter of minutes. I soldered a row of header pins to the FM transmitter module to allow me to insert it directly into a breadboard, although wires could be use as well. The audio input connections can be tied to whatever jack best fits your needs. A mini-stereo jack is ideal, but recall you will need a matching cable to plug into your MP3 player.

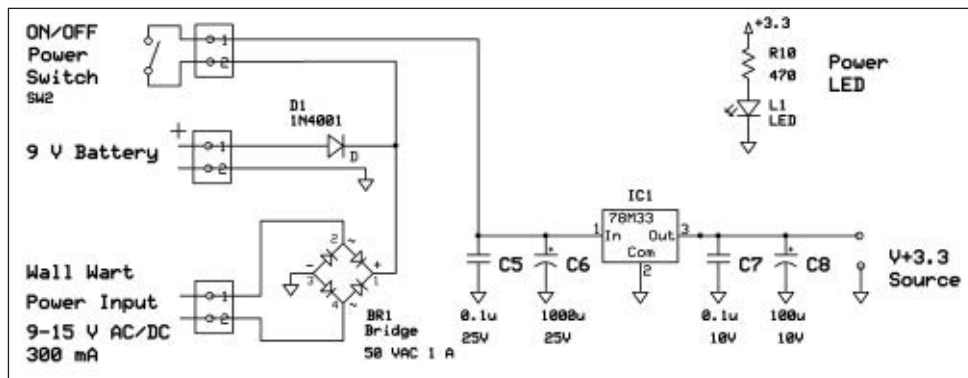
A short wire is soldered directly to the antenna pad on the module. The crystal and power supply filtering capacitor for the transmitter chip are already provided on the module. Be sure to order them separately if you order the chip without the board for your own design. There are two pull-up resistors for the I²C clock and data lines.

The Butterfly is easily programmed using its on-board

■ **FIGURE 1.** The Butterfly Broadcaster schematic. Currently transmitting on 102.1 (MHz, FM radio band). An optional audio signal generator produces a 1 kHz tone. Following filtering and attenuation, it can be used as an audio source for setup and testing.



■ **FIGURE 2.** A generic 3.3V DC power supply for the Butterfly Broadcaster can use either a 9V battery or a wall wart source.



RS-232 serial port. The transmit, receive, and ground lines should go to a small, nine-pin, female RS-232 connector. This can then plug into a standard PC serial port. An optional push button reset switch is shown in the schematic. It is useful if you wish to experiment with the Butterfly and are frequently resetting the system. For a stand-alone transmitter, it is not required.

Power Supply

The Butterfly board includes a three volt coin cell. This works well for experimenting with the system, but is not designed to provide sustained power to the transmitter chip. For this reason, an external power supply is recommended. The Butterfly board is designed to use an external power supply from 3.1 to 4.5V DC. Do NOT connect it to a 5V power supply. Although the ATmega169 chip can be powered by 5V, the board's DataFlash chip and the NS73M FM transmitter chip are both designed for a maximum of 3.6V. The power supply, therefore, provides a regulated 3.3V for the circuit. You can feed the power supply with a 9V battery or a small 9-15V AC or DC wall wart. Diode D1 protects the circuit in the event that the battery gets connected backwards. The LED is a simple power-on indicator. A generic 3.3V DC power supply is illustrated in Figure 2.

Programming the Butterfly

The Butterfly board provides three separate connectors for programming it via an RS-232 serial port, a JTAG connection, or via an AVR ISP connection. The RS-232 serial port connection is simple, and does not require the use of any additional programmers. AVR Studio 4 is the PC software — available as a free download from the ATMEL website — which loads the program into the Butterfly. The Basic program is first compiled generating a hex file, which is then downloaded into the Butterfly. This process is non-intuitive to those unaccustomed to the process, and warrants review. Download and install AVR Studio 4 following the prompts. Either hit the reset button on the Butterfly or cycle its power off and on. Doing so causes it to power-up running its internal “bootloader” program, awaiting the download from AVR Studio 4. Next, press the Butterfly

joystick inwards, and hold it in this position while starting Tools/AVR Programmer in AVR Studio 4. A new AVRprog window will pop open, after which one can release the joystick button. On the new programming window, you can browse to the location of the hex file to download (BFFMTX.HEX). Then, hit the Flash Program button to initiate the download. Hit the Exit button to disconnect

PARTS LIST

ITEM	QTY	DESCRIPTION
□ BF1	1	AVR Butterfly demo board
□ FM1	1	FM radio transmitter module breakout board, with NS73M
□ IC1	1	78M33, 3.3 V, 500 mA, fixed three terminal voltage regulator
□ D1	1	1N4001 diode (50 V PIV, 1A)
□ L1	1	Red LED
□ BR1	1	50V 1A bridge rectifier
□ R1, 2	2	4.7K, 1/8 W resistors
□ R3, 4, 8	1	33K, 1/8 W resistors
□ R5, 6, 9	1	10K, 1/8 W resistors
□ R7	1	1K, 1/8 W resistor
□ R10	1	470 ohms, 1/8 W resistor
□ C1, 2	2	1 µF, 10V, non-polarized capacitors
□ C3	1	10 µF, 10V capacitor
□ C4, 7	2	0.1 µF, 10 V capacitors
□ C5	1	0.1 µF, 25 V capacitor
□ C6	1	1000 µF, 25 V capacitor
□ C8	1	100 µF, 10V capacitor
□ SW1	1	SPST mini-toggle switch, power on/off
□ SW2	1	Mini-push button switch, uP reset

MISCELLANEOUS

□	1	DB-9 mini female RS-232 connector
□	1	Mini-stereo jack
□	1	9V battery
□	1	9V battery clip
□	1	Wall wart power supply 9-12V AC or DC, 300 mA
□	1	Case and mounting hardware Wire, solder, etc.

Digi-Key Corp — www.Digikey.com

SparkFun Electronics — www.Sparkfun.com

the Butterfly from AVR Studio 4 when the download and verify are completed. Finally, push the joystick upwards to start the program running. This is the process used when downloading any program to the Butterfly.

Additional Programs

The versatility of the Butterfly allows one to modify the provided transmitter program to incorporate revisions, modifications, and additional features. The provided transmitter program uses just a small portion of the

memory available. When not being used as an MP3 broadcaster, you can also use it as a general-purpose learning platform for microcontrollers and programming.

The Butterfly board comes with a preloaded program which allows you to display scrolling messages on the LCD, play simple music through its piezo-electric beeper speaker, display the temperature using its on-board thermistor, provide a clock/calendar display, or measure and display an external 0-5 volt DC signal (voltmeter). This program is erased when loading the FM transmitter program.

You can download this original program from the ATMEL website and download it to the Butterfly using the above technique, restoring the Butterfly to its original state. You can also use AVR Studio 4 to enter and download assembly language programs to the Butterfly. Best of all, however, Bascom-AVR has a free, demonstration version available. It is limited to 4 KB of code. You can write short programs in Basic, compile them, and download them as above.

Smaller is Better

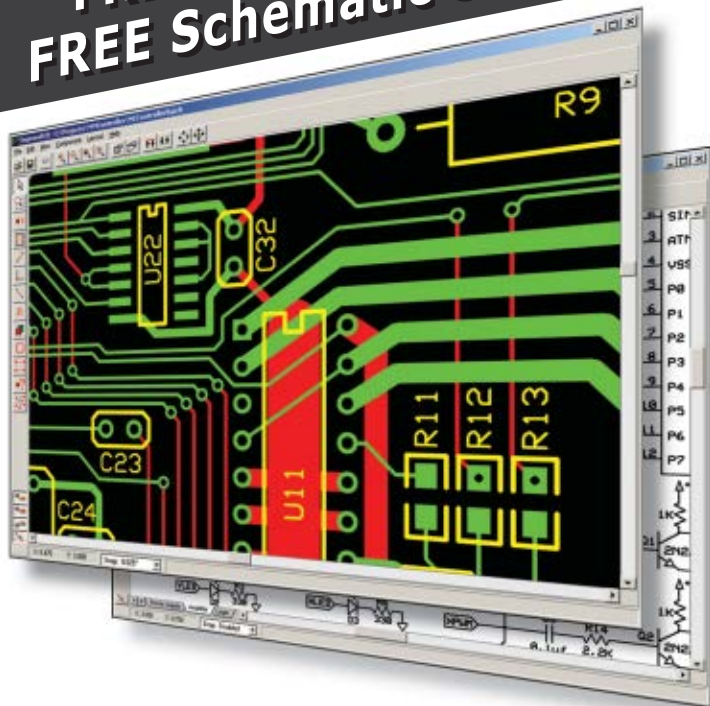
Although the Butterfly board is only the size of a credit card, this project could be miniaturized further. The Butterfly platform is perfect for providing a low-cost, small integrated processing package with which to learn the nuances of the NS73M transmitter. Given the transmitter chip's size of 7 mm x 7 mm, and equally small processors, the size of the display and the battery capacity become the size-limiting factors. If one chose to incorporate this chip within an MP3 player, these two factors also vanish, and today's MP3 players suddenly become obsolete! Where is a venture capitalist when you need one? **NV**

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ABOUT THE AUTHOR

When not practicing emergency medicine, Jay can usually be found tinkering with chips and an oscilloscope, or on the air as KD8HKD.

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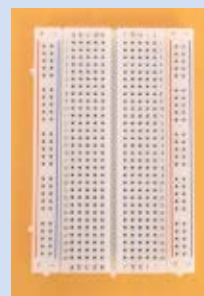
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BUILD A VOICE CHANGER

BY JIM STEWART

One day back in the 1970s, I tuned to a public television station to see an oddly dressed man fighting off a swarm of evil looking robots. It was Tom Baker as Dr. Who saving the universe from the Daleks. I've been a fan ever since. For the uninitiated, Dr. Who is a sci-fi show produced by the BBC. Daleks (shown here) are half-robot aliens that roll around saying things like "You will be exterminated!"



Recently, I came across a talking Dalek toy for sale on-line. Of course, I had to get one. Daleks have a bizarre voice, and I thought it would be fun to build a voice-changer circuit to make me sound like one (see the sidebar on voice changer circuits).

With a little research on the Internet (e.g., look up "Daleks" on Wikipedia), I found out that the Dalek voice

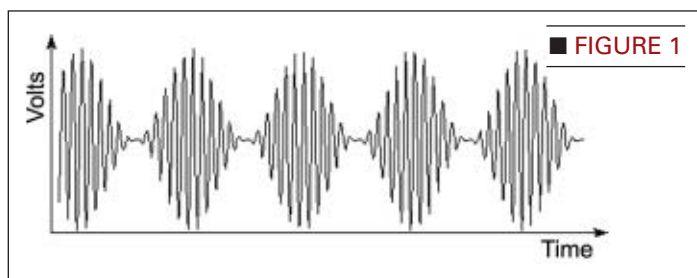
is produced by mixing an actor's voice with a fixed frequency sine wave in a ring modulator (also called a balanced modulator). I found different values for the frequency of the sine wave in different sources; the range was 30 Hz to 100 Hz. Using an oscilloscope to actually look at the voice signal from my talking Dalek toy, I saw the typical double sideband suppressed carrier (DSB-SC) wave form produced by a balanced modulator. Figure 1 shows a simplified version. The outer envelope would be the low frequency sine wave while the inner signal would be the voice.

DSB-SC

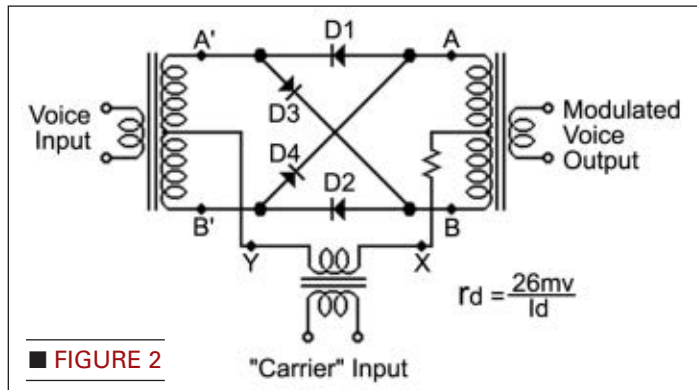
Balanced modulators are used in RF work to generate and detect signals. (When used in a detector, it's usually called a mixer.) DSB-SC is basically an AM signal, but without the carrier. Its output contains sum and difference frequencies only, which it achieves by multiplying the audio with a fixed frequency carrier.

A balanced modulator can be built in several ways. You can use an IC such as the old LM1496 which was designed for this purpose. Or, you could use a multiplier IC, such as the AD633. The 1496 requires +12V, -8V, a fist full of resistors and capacitors, and a carefully adjusted trimpot. The 633 is relatively expensive (\$8), but luckily, there are other ways to do it.

Figure 2 shows a classic four-diode ring modulator. While at first glance it looks like a bridge rectifier, closer scrutiny shows the diodes are not arranged to rectify.



■ FIGURE 1



■ FIGURE 2

Rather, the diodes are used as switches. Remember that the dynamic resistance (r_d) of a diode is approximated by $r_d = 26 \text{ mV}/I_d$.

With no current ($I_d = 0$), r_d is very high and the diode switch is open. If I_d becomes, say, 10 mA then r_d becomes 2.6Ω and the diode switch is closed. The carrier input supplies the diode current.

Referring to Figure 2, if point X is positive with respect to point Y, diodes D1 and D2 conduct and connect points A to A' and B to B', thus allowing the input to flow to the output. But if point Y is positive with respect to point X, diodes D3 and D4 conduct and connect points A to B' and B to A'. Now the input flows to the output but with a 180° phase shift. In effect, the input is multiplied by -1 and is inverted. The audio is multiplied by the carrier input. Note that the carrier current is a bipolar square wave (switches between +I and -I); you want those diodes to open and close quickly and cleanly.

Assuming all the diodes are closely matched and assuming the transformer center-taps are exactly in the middle, then the current from the carrier input will flow equally both ways from the middle of the transformers. That means there is no net flux in the transformers from the carrier, so it doesn't couple to the output; the carrier is suppressed. (In real life, some carrier will leak through; but with good design, you could get 60 dB of carrier suppression.)

I didn't want to just build a circuit with three audio transformers. What else is there? Well, another diode switch type of circuit is a balanced bridge modulator as shown in Figure 3. Resistors R_S and R_L form a voltage divider with $R_L \gg R_S$. With the diode switches open, the output is $V_{out} = [R_L / (R_L + R_S)] \times V_{in} \approx V_{in}$. With the diode switches closed, a very low resistance (R_D) is in parallel with R_L . Since $R_D \ll R_L$, we have $V_{out} \approx (R_D / R_S) \times V_{in} \approx \text{zero}$. This circuit effectively multiplies the voice signal by a unipolar square wave (switches between +I and 0): half the time $V_{out} \approx V_{in}$; and half the time $V_{out} \approx 0$.

Figure 3 is easier to build than Figure 2, but it still requires a transformer. However, if multiplying by a square wave will do the job, why not use an analog switch IC? Such ICs are inexpensive, and no transformers are required.

The Circuit

Figure 4 is a schematic of the

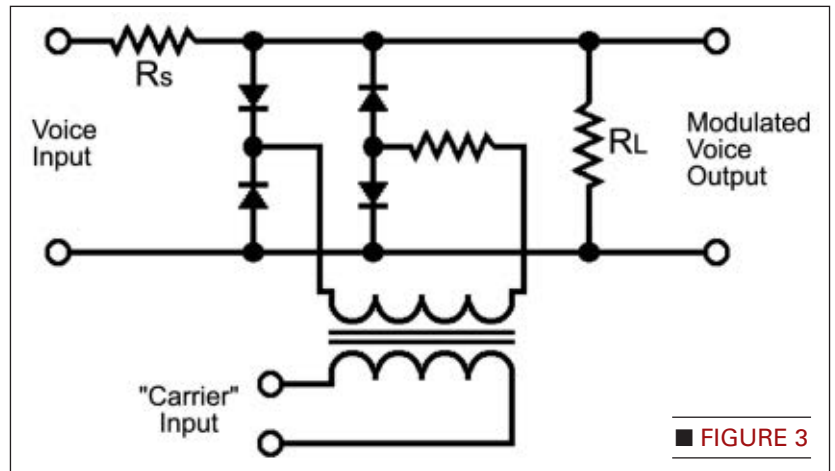


FIGURE 3

voice changer. A DC supply is connected to tie-block TB1. Diode D1 protects against reverse polarity. (I've learned the hard way that such protection is a good idea.) D2 is a green LED power indicator. Capacitor C11 decouples audio from the power rail. IC3 is a 78L05 to supply a regulated +5 volts to an electret microphone which plugs into 3.5 mm stereo jack J1. R3 connects the five volt bias to the microphone's built-in amplifier (see symbol in Figure 5) and also sets its gain.

IC4 needs both positive and negative supply rails. Since we are using a single voltage to power the board, we need to create a separate audio ground at half the supply voltage. That's done with 1% resistors R4 and R5. With respect to audio ground, actual ground looks like a negative voltage. Capacitor C6 decouples the audio ground by creating a low impedance AC path to actual ground.

The power supply you use for this project should be

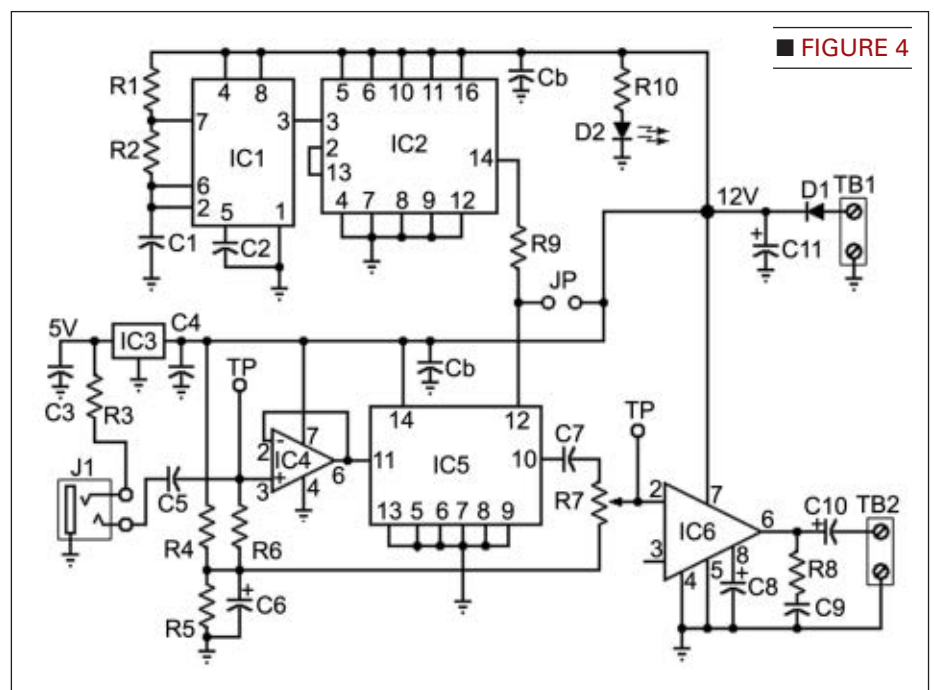
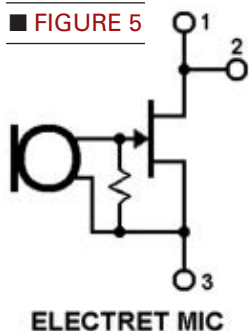
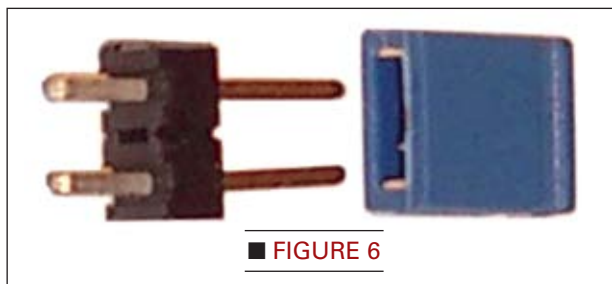


FIGURE 4

■ FIGURE 5



ELECTRET MIC



■ FIGURE 6

well regulated. Any hum on the DC from the AC mains will be amplified. C11 is there to

remove audio; it's not big enough to remove AC mains hum. To use an unregulated wall-mount supply, you could use the circuit described in my upcoming article on switching regulators.

The voice signal from the microphone is coupled via C5 to buffer op-amp IC4. Since an electret mic produces a relatively large signal, IC4 is configured for unity gain. To use a crystal type mic, IC4 would need to be reconfigured to supply some gain. R6 references the input of IC4 to the audio ground. Note that C5 allows the mic to use real ground while IC4 uses audio ground. The output of IC4 goes to IC5, a CD4066 analog switch. I used a 741 for IC4 because they're inexpensive, easily obtainable, and I had a bunch. You can use a better op-amp (e.g., LF411) if you have them.

IC1 is a CMOS 555 timer chip running as an astable. IC2 is a CD4027 dual JK flip-flop which divides the 555 output by four to produce a square wave. You

can set the frequency that sounds best to you with C1. I used 0.022 μ F to get a carrier frequency of about 50 Hz.

The Q output of IC2 is the control signal for the analog switch, so it's the "carrier" that modulates the audio by turning the switch on and off. The modulated audio from IC5 goes to power-amp IC6 via potentiometer R7,

the volume control. Note that R7 is also referenced to audio ground. C7 is required since the input of IC6, an LM380, is referenced to actual ground. The modulated audio output is capacitively connected to a loud speaker via terminal block TB2, and easily drives an 8W speaker.

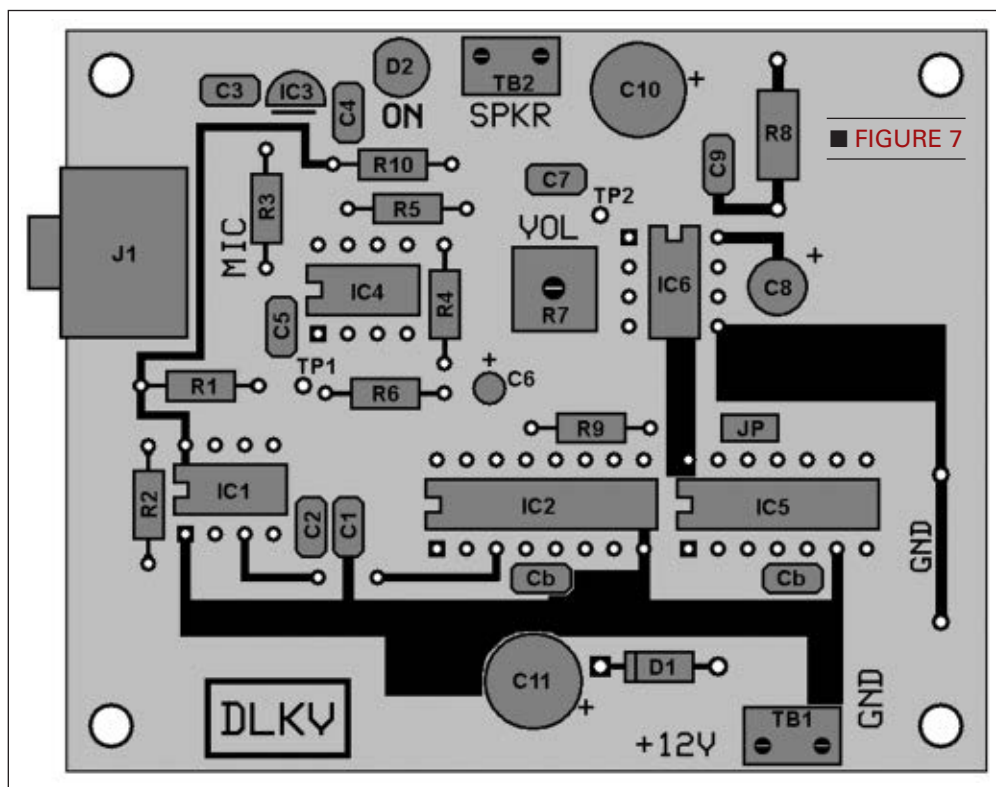
JP (see Figure 6) is a removable jumper on the printed circuit board (PCB) that allows the supply voltage to be applied directly to the control input of IC5 (pin 12). That has the effect of overriding the modulation from IC2 and forcing the analog switch to remain closed. Resistor R9 is required to isolate the output of IC2 when the jumper is in. With the jumper out, R9 has no effect since IC2 and IC5 are CMOS chips. With the jumper in place, the voice changing effect is disabled and the board performs as a plain audio amplifier. The jumper mounts on a two-pin header soldered to the board.

Construction

The PCB (DLKV) is double sided and measures 2.5 by 3.2 inches. The layout of the component side is shown in Figure 7. Four 1/4" corner holes provide a way to mount the board. Power is run separately to the input and power-amp sections to avoid feedback through the power rail. Likewise, each section has a separate connection to ground.

Test Points

I've learned over the years that it's very useful to design test points into PCBs. This board has two test points. TP1 allows you to connect a scope and look at the signal coming from a microphone. TP2 allows you to look at the signal going into the power-amp. It's also helpful to provide a convenient bus to connect the ground leads of multimeters and



■ FIGURE 7

oscilloscopes. There is a strip of copper near the edge of the board that connects to ground. There is a hole at each end of the strip. Take a bare piece of solid wire, make a 90° bend in both ends, and solder it to the holes so that the wire is spaced about 1/4 inch above the board. There's your ground bus.

Using IC Sockets

When assembling a newly designed PCB, I use sockets for the ICs in case I blow a chip due to a layout error. Once I know the board design is okay, I solder the chips directly to the board. Sometimes I'll keep a chip such as an op-amp in a socket so that I can swap in various types to see if there is any difference in performance.

Mounting in an Enclosure

Microphone jack J1, volume control R7, and jumper JP are all board-mounted. To mount the project in an enclosure, they must be replaced with panel-mounted types and connected back to the PCB with short lengths of hook-up wire. You would replace JP with a switch.

Testing

Before applying power, clean the board with rubbing alcohol and an old tooth brush and give it a careful visual inspection. Look for the usual suspects:

- Bad solder joints
- Broken copper traces
- Shorted copper traces (especially IC pads)
- Reversed polarity on capacitors
- Wrong value capacitor
- Diodes in backwards
- ICs in backwards
- Wrong IC in a socket
- IC socket lead bent under and not in hole
- Missing components (especially monolithic caps)

Once you're sure there are no obvious problems, measure the resistance from +V to ground. If it's low or zero, there's a problem. Assuming you used sockets, pull the chips out one at a time. If the short goes away, you've located the problem area. If it doesn't go away, look for shorted traces.

With the jumper in, set volume to

minimum, plug an electret mic into J1, attach a loudspeaker (or headphones), and attach 12 volts to TB1. Make sure the loudspeaker is pointing away from the microphone. Verify that the LED is lit.

Speak into the microphone as you gradually increase the volume to a comfortable level. Verify that the circuit is amplifying. Then remove the jumper as you continue to speak and verify that your voice is modulated.

Wrap-Up

Some fun things you can do with this project are to put "LEAVE A MESSAGE OR YOU WILL BE EXTERMINATED!" on your answering machine or tell the neighbor "GET YOUR DOG OFF MY LAWN OR YOU WILL BE EXTERMINATED!" The possibilities are endless. **NV**

The PCBs and/or a complete kit for this project can be purchased through the *Nuts & Volts* Webstore at **www.nutsvolts.com** or call our order line at **800-783-4624**.

Continued ...

PARTS LIST

ITEM	DESCRIPTION
<input type="checkbox"/> IC1	555C Timer
<input type="checkbox"/> IC2	CD4027 Dual JK Flip-Flop
<input type="checkbox"/> IC3	78L05 5V Regulator
<input type="checkbox"/> IC4	741 Op-amp
<input type="checkbox"/> IC5	CD4066 Analog Switch
<input type="checkbox"/> IC6	LM380 Power-Amp (eight-pin DIP)
<input type="checkbox"/> R1,R2	121K, 1%, 1/4W
<input type="checkbox"/> R3,R6,R9	15K, 5%, 1/4W
<input type="checkbox"/> R4,R5	2K, 1%, 1/4W
<input type="checkbox"/> R7	25 kΩ, Single-Turn, PCB-Mounted Potentiometer
<input type="checkbox"/> R8	2.7 Ω, 5%, 1/2W
<input type="checkbox"/> R10	1 kΩ, 5%, 1/4W
<input type="checkbox"/> C1	0.022 μF, Monolithic Ceramic
<input type="checkbox"/> C2,C4,C9	0.1 μF, Monolithic Ceramic
<input type="checkbox"/> C3,C5-C7	1 μF, Monolithic Ceramic
<input type="checkbox"/> C8	10 μF, 25V, Aluminum Electrolytic
<input type="checkbox"/> C10	100 μF, 35V, Aluminum Electrolytic
<input type="checkbox"/> Cb	0.1 μF, Monolithic Ceramic for Bypass (decoupling)
<input type="checkbox"/> D1	1N4001
<input type="checkbox"/> D2	GRN LED
<input type="checkbox"/> JP	Two-pin Header and Removable Jumper
<input type="checkbox"/> J1	3.5 mm Stereo Jack, PCB Mounted
<input type="checkbox"/> TB1,TB2	Terminal Block, PCB Mounted, Two Contacts, RadioShack part 276-1388 (also Molex 39890-0302 or equivalent on 0.2 inch spacing)

VOICE CHANGER CIRCUITS

Voice

How is it that we can recognize a person by their voice? You could answer that each person's voice has a distinctive pattern of qualities that we can hear. But how would you quantify those qualities so that they could be measured objectively? One answer is summed up by the word spectrum.

A microphone converts voice into AC signals that we can observe with an oscilloscope. For example, four spoken words might look something like Figure SB1.

We can see some sort of pattern in Figure SB1, but how do we get our hands on it? After all, to make a voice changer we need to alter the pattern so it sounds like someone else spoke the words. Which brings us back to spectrum.

Frequency Spectrum

Obviously, the signal in Figure SB1 is some complicated function of time. But back in 1807, a fellow named Joe Fourier wrote a paper showing that, mathematically, such complicated signals can be written as a sum of simple sine waves. Each of the component sine waves would have a specific amplitude and frequency. Just like the rainbow of colors in white light, that collection of sine waves is the frequency spectrum of the signal. Because of slight differences in our vocal systems, when I say the word "tomato" it will have a

slightly different spectrum than when you say "tomato." Our brains can distinguish those differences.

Changing a Voice

So, to make a voice changer, all we need to do is take the signal from a microphone, alter its frequency spectrum, and put it out a loudspeaker. How can we do that? Let's look at a few techniques (there are more than these).

Compression

One aspect of voice that contributes to its spectrum is dynamic range: As we speak, our voice gets louder and softer. If we never varied the loudness of our voice, it would sound mechanical. So, one technique for voice changing is to use compression. With an automatic gain control (AGC) circuit, we can amplify a signal when it's soft and attenuate it when it's loud. AGC circuits are commonly used in commercial two-way radio systems used by emergency personnel.

Figure SB2 shows one way of making a compressor. It relies on our old friend, the diode. The amplifier is set to a fixed gain. The input goes through a voltage divider formed by resistor R1 and r_d , the dynamic resistance of the diode. The current through the diode (I_d) is controlled by the amplitude of the output, and $r_d = k / I_d$. (This is a conceptual circuit; more is required to make it practical.)

Fuzz

In two-way radios, they want to preserve the quality of the audio so that it's understandable. But in a voice changer, a little distortion might be a good thing. So in addition to AGC, we can add a little "fuzz" to our voice by clipping the peaks of the sine waves by using a limiter. Clipping makes the sine waves look more like square waves, which adds high-frequency harmonics to the voice signal. Figure SB3 shows a simple limiter circuit. Using three-diode strings in the feedback path makes it a soft limiter, meaning that the corners of the wave tops are rounded. A hard limiter would produce an actual square wave.

Resonance

Some interesting effects are produced by inserting a resonant peak into the middle of the audio spectrum. This can be done with a Wien-bridge circuit as shown in Figure SB4. The negative feedback is set to a level high enough to prevent oscillation. As you decrease negative feedback, the effects become greater.

With proper resistor values in the negative feedback path, you will avoid oscillation over the range of the potentiometer. Adjusting the feedback sets the Q of the circuit, and that sets the bandwidth.

Mixing

Using band-pass filters, the audio spectrum can be divided into several subranges. The amplitude of the signals within each band can then be adjusted to change the sound of the

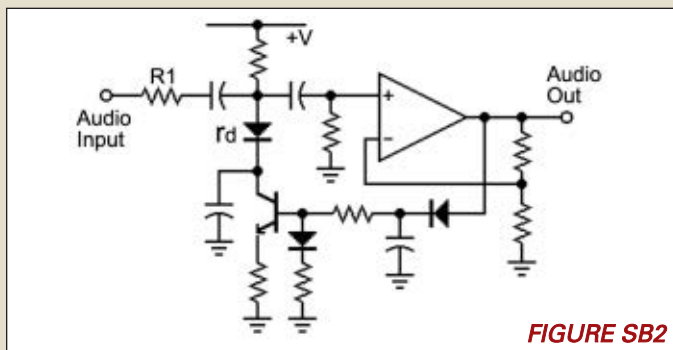
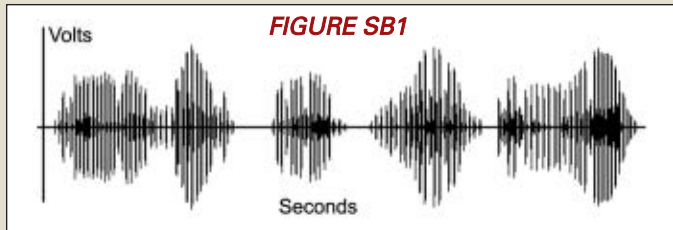


FIGURE SB2

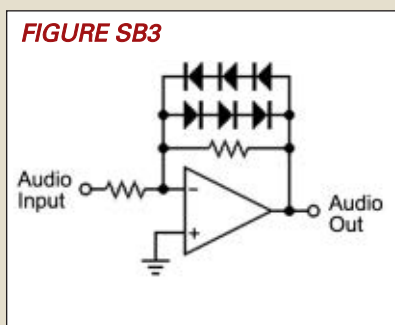


FIGURE SB3

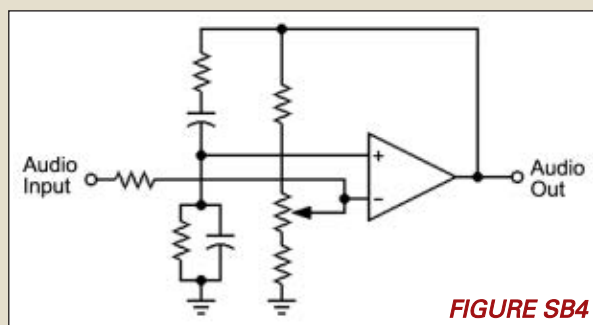


FIGURE SB4

voice (see Figure SB5). This is what is done at a mixing desk in a recording studio, where the term "mixing" refers to a linear process of addition. The mixing done by a modulator is a non-linear process of multiplication. Non-linear mixing creates new frequencies; linear mixing does not.

Holtek HT8950 IC

The HT8950 "Voice Modulator" was designed to be used in voice changers. It allows you to shift the entire voice spectrum up or down in frequency. It can provide an 8 Hz vibrato. It can also create what they call a "robot voice." The schematic in Figure SB6 is adapted from the HT8950 datasheet. This chip is found in several voice changer kits currently being sold.

Other ICs

Princeton Technology makes the PT2399 "echo audio processor" IC which (as you might guess) adds echo to an audio signal. The amount and duration of the echo can be adjusted. It uses A/D conversion, digital delay, and then D/A conversion. Other companies make similar devices.

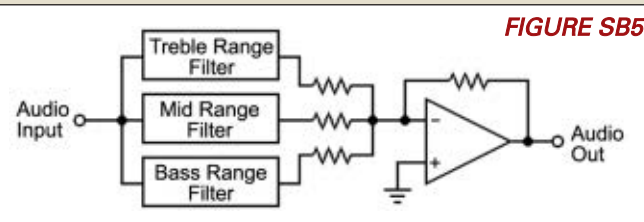


FIGURE SB5

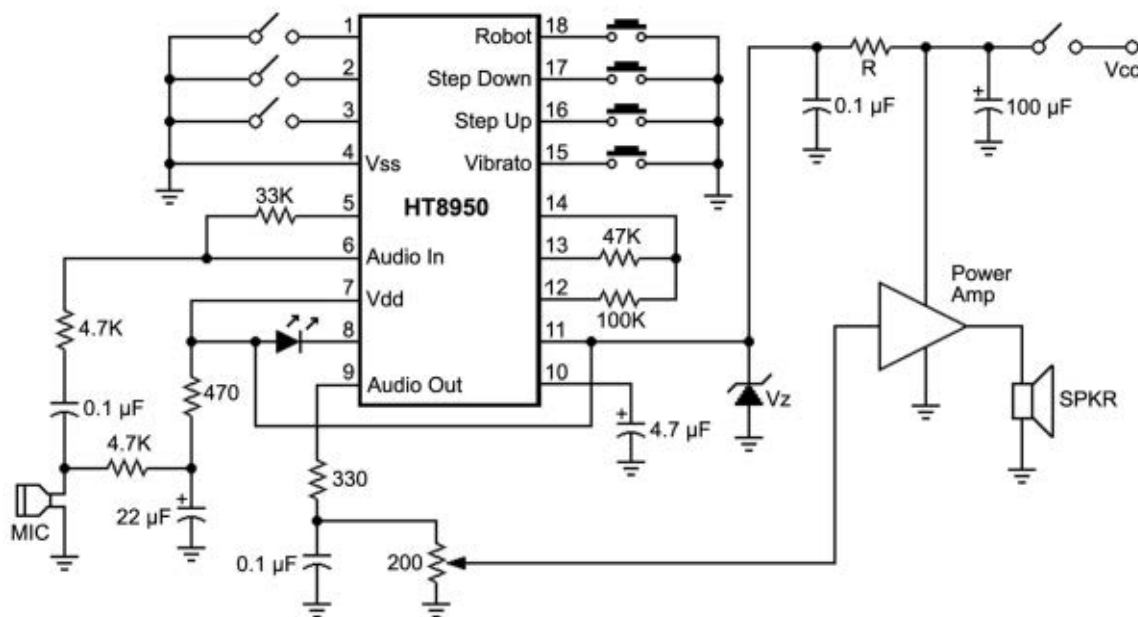


FIGURE SB6

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MICROCONTROLLERS GIVE SLOT CARS A BOOST

BY JOHN MOUTON

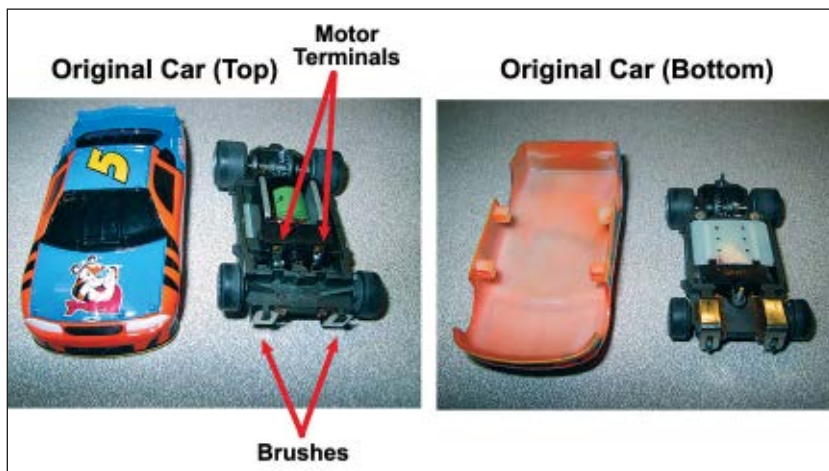


Microcontrollers are used in many different applications — motor control being one of them. So why not put a motor on something fun, like a slot car? This article will show how to turn an 18 volt, brushed DC-motored slot car into a micro-controlled super car using the PIC12F683 microcontroller. We will give the car adjustable speed control (a throttle!!), brakes (Midas doesn't make them that small), and the ability to read the track and know where all of the turns and straight-aways are. You can even set your track up so that you can run a modified slot car against a non-modified slot car, and see who wins.

Everything you need to build this project — schematics, photos, references, sources, and a list of parts — is included. The possibilities for this project are endless — you can make it as easy or as complex as you want. My only warning to you is that once you start, it will be very hard to stop.

Getting started is easy. You can go to almost any hobby shop around or online to purchase a basic electric

slot car set with a starting price around \$30. Purchase one that you feel is right for you, as long as the track and cars can take 18 volts DC and the slot cars have brushed DC motors. The track can be as long or as short as you want, and you can always add pieces to it later. For this article, I chose an oval layout for simplicity and explanation purposes. The exact slot car track set used in this article is the NASCAR Winners-cup set (Part # LIF9544) purchased from www.mascr.com for \$59.95.



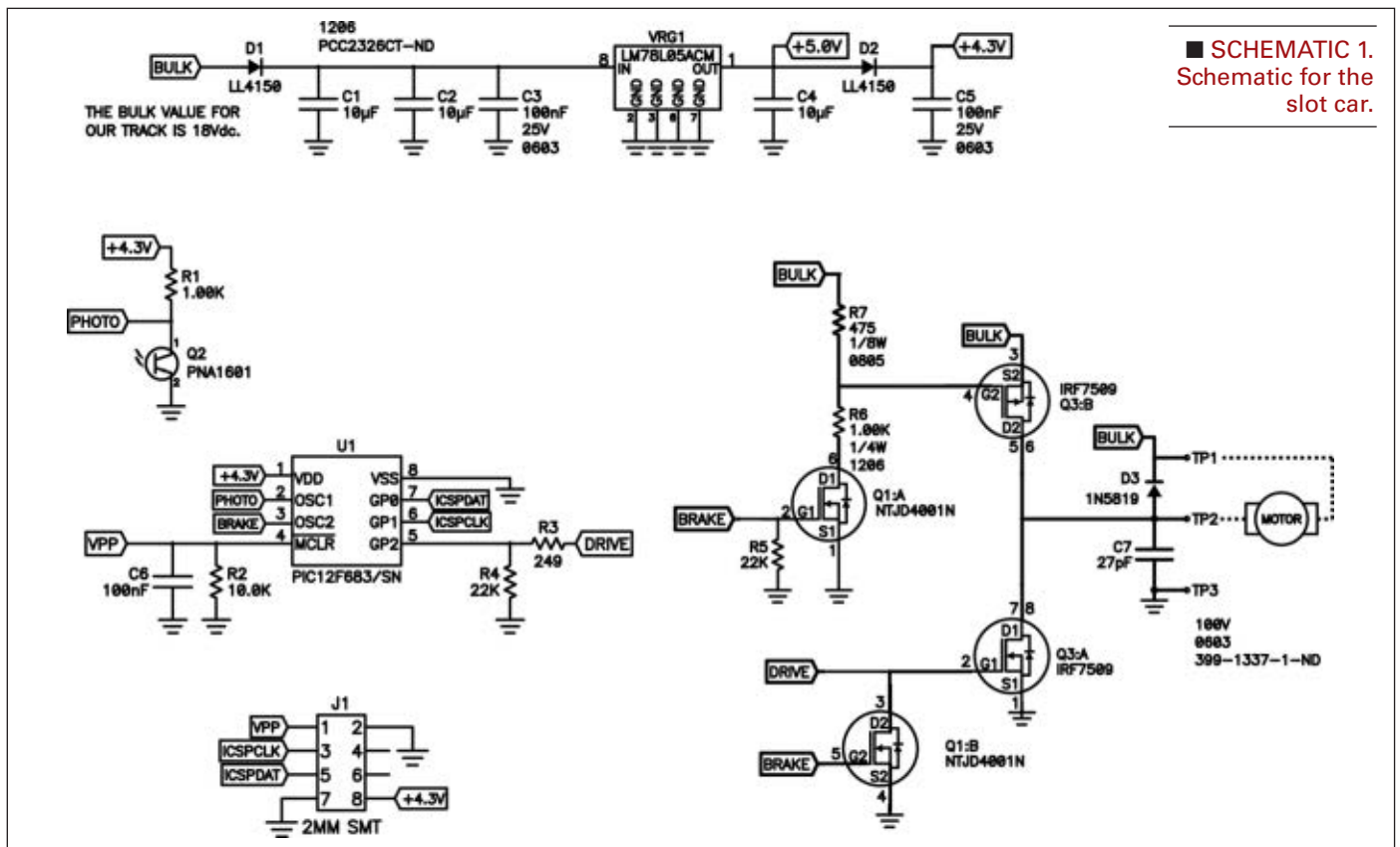
Start Your Engines!

To begin with, take a look at Figure 1. If you look closely at the original slot car with its cover off, you will see that each terminal of the motor

■ **FIGURE 1.** Top and bottom views of the slot car — right out of the box.

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physically connects to a corresponding brush that rubs against a metal strip embedded into the track, which carries the same electrical potential when power is applied. In Figure 1, the brushes are connected to the motor terminals. It is between the brushes and the motor terminals that we will connect the microcontroller circuit.

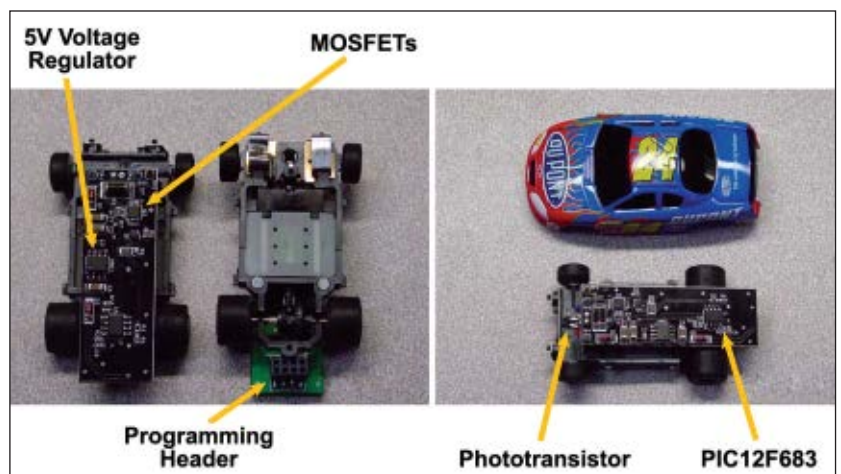
As Schematic 1 and Figure 2 show, we must connect our new microcontroller circuit between the two brushes and the DC motor. Schematic 1 shows the voltage regulator at the top, the half-bridge drive circuit with FET drivers to the right, and the PIC12F683 microcontroller, photo transistor, and programming header to the lower left. Figure 2 shows the slot car after the microcontroller drive circuit was built and installed on to the slot car. The circuit board can attach to the car's frame using a few small (and I do mean small) drops of super glue.

In Schematic 2, D1 and D2 are the infrared (IR) LEDs that are read by the photo transistor on the slot car (Digi-Key part #QEE123-ND). The 100 ohm (0603 sized) resistors can also be purchased through Digi-Key.

Let's sit back and think about exactly what we want to do. We want to run the motor in the forward direction, with the ability to control the speed and to electrically brake or

stop the motor. How can we drive a brushed DC motor to accomplish these tasks? By using a half-bridge drive circuit. You can also use a full-bridge drive circuit, but to keep the overall circuit small, simple, and less expensive, a half-bridge circuit will give us exactly the performance we want. This type of circuit will also give us the ability to drive the motor forward and electrically brake/stop the motor. However, for this application, I found only one major drawback with using the half-bridge drive circuit – as there are two MOSFETs controlling the switching inside the half-bridge circuit, there is a possibility of both MOSFETs being switched on (conducting) at the same time. This situation will create a condition where current will flow through

FIGURE 2. Slot car with microcontroller drive circuit installed.



A SHOCKING EXPERIENCE

I feel I need to share an experience I had involving electrical safety — specifically, one involving knowing the difference between AC and DC. When I was a kid, I learned the difference between AC and DC on the very same type of slot car track set. I was sitting on my bedroom floor racing two slot cars against each other with a reo-stat trigger controller (standard equipment with most slot car track sets) in each hand, and found that they both maxed out at about the same speed. Of course, I had to make one faster than the other, but how could I do this? At that stage of my life, all I knew about electricity was that I could take the positive and negative ends of a battery and connect them to a motor, and the motor would have power. So, with the utmost confidence, I applied the same concept to this application. I took an old lamp cord with a plug on one end and two stripped

wires on the opposite end of the three foot chord. As I held the slot car motor leads to the stripped wire end of the lamp cord, I plugged it into a wall outlet. With the sparks, the smoke, the loud thump of the house's main circuit breaker being thrown, a really bright light appearing in front of my face, and all the hair on the back of my neck standing straight up, I yanked the cord out of the wall.

Just then, my Dad rushed into the room with a look of stark terror on his face as he realized what I was doing. It was also at that moment that I realized the only thing that kept me from spending all my nine lives was a thin piece of plastic that covered the motor of the slot car. That was now a smoking blob of plastic stuck to the end of a lamp cord. So, remember the current flowing from the wall to the black box (the AC-to-DC adapter) on the end of the cord coming from the track is AC. The current flowing from the adapter to the track and into the slot car motor is 18 volts DC.

both MOSFETs and the motor, thus shorting the bridge supply and damaging the circuit, slot car, and track. This is commonly called “shoot-through current.” As Schematic 1 shows, in order to prevent having shoot-through current destroy our application, we need to add a couple of FET drivers to our circuit.³

A FET driver circuit is a separate MOSFET with a small resistor network that will cause a delay in the switching on and off of one MOSFET used in the half-bridge drive circuit. Thus, you must have a separate FET driver for each MOSFET inside the half-bridge drive circuit. Basically, you are creating a “poor man’s” dead-band delay. But, depending upon the microcontroller you use, the microcontroller could have a dead-band delay feature already designed into it. The PIC12F683 used in this article does not have this feature, so I created it externally.

FET Selection, Control and Protection

Now that we know how we are going to drive our brushed DC motor, we must control the motor’s speed. We will do so using the PIC12F683. However, this microcontroller uses five volts DC to operate. This means that we must use a voltage regulator circuit to not only supply 18 volts DC to the track, but to also supply five volts DC to the microcontroller (again see Schematic 1 and Figure 2). This microcontroller, like

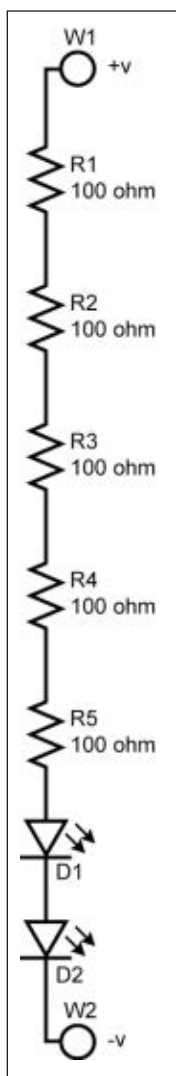
many others, has a peripheral built into it called a Capture/

Compare/Pulse-Width Modulation (CCP) module. The Pulse-Width Modulation (PWM) portion of this module will enable us to generate a modulated signal of varying frequency and a duty-cycle that will allow us to vary the voltage across the motor, thus varying its speed.⁴

The voltage across the motor, or average voltage, is equal to the voltage supply (BULK, shown in Schematic 1) multiplied by the duty cycle (duty cycle = pulse width/period) of the PWM signal. Therefore, PWM control works by switching the voltage supplied to the motor on and off very rapidly, thus converting it to a square wave signal giving the motor a series of power “kicks.” Every time the PWM signal reaches and maintains its set voltage, the MOSFET turns on. When the PWM signal drops to zero, the MOSFET turns off, like a switch. So, every time the MOSFET is on, the motor will rotate. By adjusting or varying the signal’s duty cycle, you vary the speed of the motor, because 100% duty cycle equals 100% speed of the motor.

Now, as we are talking about a modulated signal, we should discuss how frequency affects the signal. As you read through the PIC12F683 datasheet, you will see that the PWM signal will have a PWM frequency. As this frequency increases or decreases, the performance of the MOSFETs inside the half-bridge drive circuit will vary. This means that, as a MOSFET switches on and off (or vice versa), it has a transitional period or an “unknown state” that occurs. And, during this unknown state, the MOSFET will dissipate heat. So, the more you increase the frequency, the more the MOSFET will switch on and off, and the more unknown states will occur. Thus, more heat will dissipate.

In some applications, this may not be a problem. However, it could be a limitation for the slot cars if we want to run them at higher speeds. There are a couple of ways to lower the amount of heat dissipated by the MOSFETs. One, buy a better MOSFET with a lower gate charge time, which will be relatively more expensive. Two, add FET drivers, as I have done in this project.³ Knowing



■ **SCHEMATIC 2.**
Track sensor.

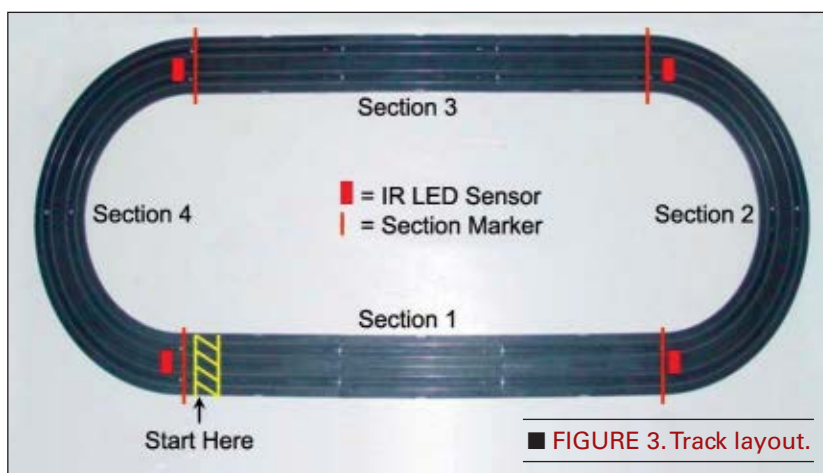
that the frequency of a PWM signal will affect the MOSFET's performance, how do we decide what is a good PWM frequency to use? There are four considerations to keep in mind when choosing a PWM frequency:

- 1) **The heat dissipated in the MOSFET.** As stated in the previous paragraph, as frequency increases, the more time the MOSFET is in a transitional or unknown state. This transition state occurs when MOSFETs switch from on to off, or vice versa. Thus, the more heat the MOSFET will dissipate.
- 2) **The responsiveness of the motor.** A motor will respond faster and better to changes in the PWM duty cycle when the PWM signal is operating at higher frequencies. As you set up the PWM module in the microcontroller, adjust the PWM frequency up and down, and see how the slot car's performance changes.
- 3) **The sound generated by the motor.** When a motor operates within a certain frequency range (about 20 Hz to 4 kHz), the motor will make a very distinctive hum or whining sound. So, to avoid this whining of the motor, set the PWM signal frequency at or above 4 kHz.
- 4) **The speed at which the motor is operating.** This consideration will be more dependent upon your motor-control application. If your motor will be running at lower speeds, you will want a higher PWM signal frequency, thus giving you a more constant motor torque. If your motor will be running at higher speeds, use a lower PWM signal frequency for less constant motor torque.

Basically, when choosing a PWM signal frequency it essentially comes down to trial and error. Pick a frequency based upon these four considerations and try it out. Adjust the frequency higher or lower, and see how it affects the performance of the motor. (Refer to the Slot Car Program on the *Nuts & Volts* website — www.nutsvolts.com — to see an example of how I set up the PWM module of the PIC12F683 microcontroller.)

The Car Detection Scheme

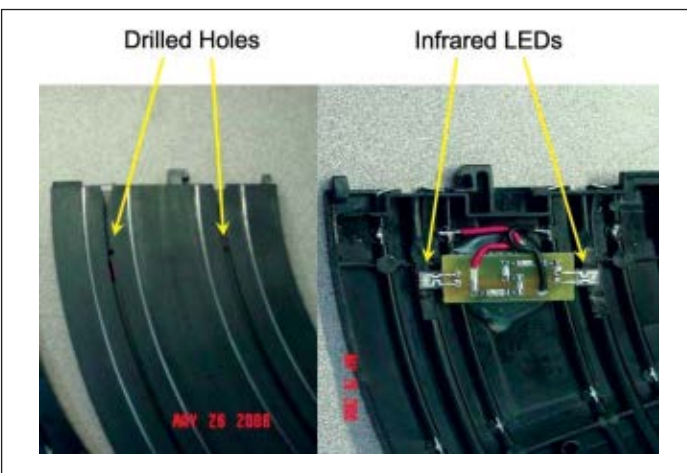
At this point, we know how we are going to drive and control the speed of the slot car motor, but what about the track? How do we modify the track so that the microcontroller on the slot car will know what part of the track it is on? First, build the track into a configuration that you are happy with. Then, draw that same track configuration on a piece of paper and mark the areas that are straight-aways, turns, and other areas that the car needs to slow down for. As Figure 3 shows, you now know how many sections you have, where you



will need to control the speed of the motor, and where you will need to put track sensors. Keep in mind that in an area where you need to control the motor speed, say a turn, you will need a track sensor at the beginning, so you can slow the car down going into the turn, and one at the end so you can accelerate out of the turn. The track sensor is a very simple sensor circuit that will use an IR LED to turn off a photo transistor mounted on the front of the slot car (see Schematic 2 and Figures 2 and 4).

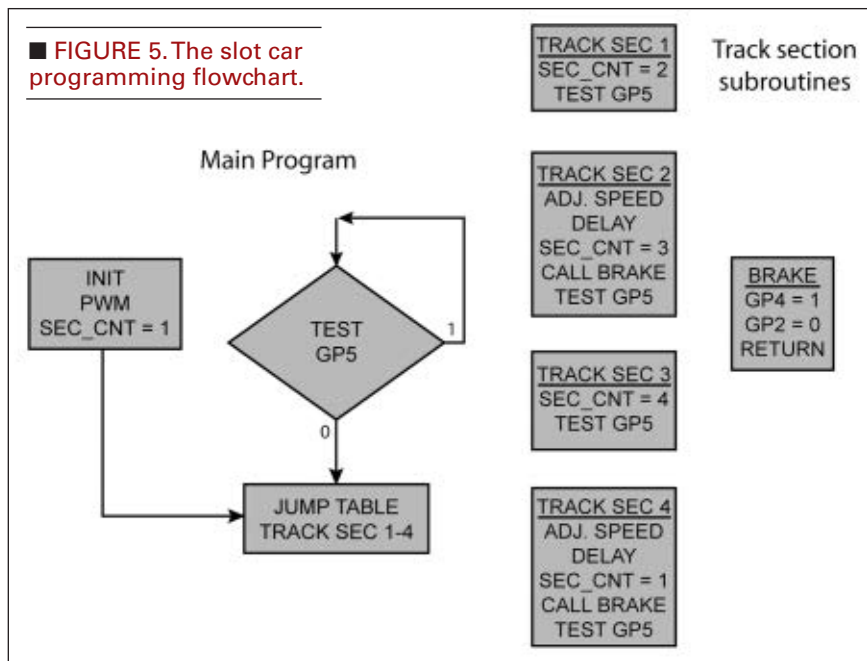
The track in Figure 3 was divided into four sections, with Section 1 being the starting point and the first straight-away. Section 2 is turn one, with a sensor at the beginning and the end. Section 3 is the second straight-away, and Section 4 is turn two with a sensor at the beginning and the end. The white arrow indicates the direction of traffic flow, beginning at the starting line.

After marking the location of where the track sensor will be located, drill two small holes in the track as shown in Figure 4, so that as the slot car drives on the track, the photo transistor will read 18 volts DC until it drives over the track sensor. At this point, the photo transistor on the slot car will read and send 0 volts DC, a binary zero or low, to the microcontroller telling it to brake, slow down, or accelerate, depending upon what section of the track the sensor is located. Then, after passing over the track



■ FIGURE 4. How to install the track sensors.

■ **FIGURE 5.** The slot car programming flowchart.



SOURCES

Slot car sets, cars, and track components: mascr.com; oakridgehobbies.com; kensclassicslots.com; slotcarworld.com; scalextric.com.

Circuit components: DigiKey.com.

Programming environment and interface tools: Microchip Technology, Inc.; www.microchip.com.

Printed Circuit Boards: expresspcb.com; circuitexpress.com.

Vehicle and Track Control Code

Next, we are ready to program the microcontroller. The main program will consist of an initialization of the microcontroller, the setup of the PWM module, and the track section counter. The track section

sensor, the photo transistor will go from reading 0 volts DC back to reading 18 volts DC until it passes over the next sensor. You may need to do some custom fitting to get the track sensor to fit under the track section so that the track will lay flat on whatever surface you have it on. A few minutes with a Dremel tool will work great.

Next, hot glue the track sensor in place and solder the positive end of the track sensor circuit (the red wire) to the 18 volt metal strip on the outside lane. Solder the negative end of the track sensor circuit (the black wire) to the 18 volt metal strip on the inside lane of the track (see Figure 4 and Schematic 2).

The photo on the left in Figure 4 shows where to drill holes in the track so that the IR LEDs can be detected by the photo transistor on the slot car. The photo on the right shows the track sensor hot glued to the bottom of the track section, so that the IR LEDs are directly over the drilled holes. The track sensor is soldered to the positive rail of the inside lane and the negative rail of the outside lane. You may have to lightly sand down some of the plastic underneath the sensor so it will sit flush under the track.

counter will be a basic counter that will start from one to four every time the slot car passes through a section of track. So, as the slot car starts from the starting line in Section 1, the section counter in our source code will start at one. Then, the code will go through a jump table that will take it to a specific track section subroutine based upon the value of the section counter. With the section counter having a value of one, the source code will jump to track section subroutine one and execute all instructions within that subroutine, including incrementing the section counter. Next, it will return to the main program, where it will go into a search loop (TEST GP5) continuously looking for a 0 volt DC drop, a binary zero or low, from the slot car passing over a track sensor. After reading a track sensor, the program will go to the jump table and, based upon the value in the section counter, jump to that track section subroutine. This process will continue until the program executes the subroutine for Section 4, where it will reset the section counter back to one and the program starts over (see Figure 5).

Figure 5 shows the overall flow and order of the slot car program/source code. I structured the program this way to make it easier to expand the jump table and add subroutines for each new section of track (with sensors) you may want to add in the future.

As you add more track sections, the number of track section subroutines in your program will increase proportionally, and the jump table will also expand accordingly. Don't be discouraged if the slot car's performance isn't as ideal as you expect from the start. You will have to adjust the program delay times and duty cycle values in order for the slot car to run at its best. To compose and debug your microcontroller source code, you can use the MPLAB® IDE (Integrated Development Environment) which



■ **FIGURE 6.** Finished project.

can be downloaded for free from Microchip's website (www.microchip.com). For this project, all you have to do is open the slot car program in an MPLAB project and assemble the source code.

You will also need a programmer/debugger interface so that you can program the slot car via the programming header (see Schematic 1 and Figure 2). The MPLAB ICD 2 Module (part #DV164007) for \$189.99, PICKit™ 2 Starter Kit (part #DV164120) for \$49.99, or PICKit 1 Flash Starter Kit (part #DV164101) for \$36 can be used to interface between your computer and the microcontroller on the slot car drive circuit. Keep in mind that each of the following programming interface kits will require a different programming header on the circuit board that will attach to the slot car. For this project, I used the PICKit 1 Flash Starter Kit, so the header you see in Figure 2 will connect to the PICKit 1. All of these devices can be purchased from Microchip's website.

In Conclusion

Basically, all you're doing is taking an existing electric slot car set and giving it some intelligence by installing a microcontroller circuit between the voltage source and the brushed-DC motor. Then, by putting IR LED sensor circuits under certain sections of the track and programming the microcontroller to read these sensors, you're giving the slot car a way of knowing where it is and what to do while it is there.

Figure 6 shows the completed project with all four track sensors in place, and both modified and unmodified slot cars on the track ready to race. Before starting this project, I knew very little about slot cars. After building this project, I found that I learned a lot and was very pleased with the final result. The set performed great for what it was programmed to do, but it still has limitations,

REFERENCES

- 1) Reston Condit, Application Note #AN905, "Brushed DC Motor Fundamentals;" DS00905A; Microchip Technology, Inc., © 2004.
- 2) Mike Rylee, Application Note #AN893, "Low-Cost Bidirectional Brushed DC Motor Control Using the PIC16F684;" DS00893A; Microchip Technology, Inc., © 2003.
- 3) Jamie Dunn, Application Note #AN898, "Determining MOSFET Driver Needs for Motor Drive Applications;" DS00898A; Microchip Technology, Inc., © 2003.
- 4) PIC12F683 Datasheet, DS41211C; Microchip Technology, Inc., © 2006.

such as no reverse or changing lanes.

In Figure 6, the microcontrolled slot car is on the inside lane and the unmodified slot car controlled via the handheld rheostat is on the outside lane.

Being an electrical engineer, my next thought on this was to make it bigger and better. After spending an extended lunch hour at a local hobby shop, I found that you can get larger slot cars with more track options (take a look at www.scalextric.com) such as side-swipe sections, lane changes on straight-aways and in turns, and pit-stop sections. Single lane setups for cars or motorcycles also exist. With a little modification to the brushes on the cars, you can give the slot cars the option of reverse. This would involve using a full-bridge drive circuit instead of a half-bridge.

As you can see, the options are endless. So, before I leave you to hours of fun, my only advice is to include family and friends, and plan out your ideas before you implement them. **NV**

PARTS LIST

ITEM	COMPONENT NAME	QTY	PATTERN NAME	VALUE
□ C7	CAP-CRCW0603	1	CAP0603	27 pF
□ C3, C5, C6	CAP-CRCW0603	3	CAP0603	100 nF
□ C1, C2, C4	CAP-CRCW1206	3	CC1206	10 µF
□ J1	CNN-HDR-2MM-2X4-SMT	1	CNN-HDR-2MM-2X4	2MM SMT
□ D3	DIO-1N5817-MELF-DL41	1	DIO-MELF-DL41	1N5819
□ D1, D2	DIO-LL4150-MINI-MELF	2	DIO-MINI-MELF-GLASS	LL4150
□ Q3	FET-IRF7509-NPCH-DUAL-MICRO-8	1	MICROMAX-8-PIN	IRF7509
□ Q1	FET-NTJD4001N-NCH-DUAL-SOT-363	1	SOT-363	NTJD4001N
□ U1	ICP-PIC12F629/SN	1	SOIC-8PIN-150", PIC12F683/SN"	
□ R1	RES-CRCW0603	1	RES0603	1.00K
□ R2	RES-CRCW0603	1	RES0603	10.0K
□ R4, R5	RES-CRCW0603	2	RES0603	22K
□ R3	RES-CRCW0603	1	RES0603	249
□ R7	RES-CRCW0805	1	RES0805	475
□ R6	RES-CRCW1206	1	RES-CRCW1206	1.00K
□ Q2	TRS-PHOTO-PNA1601M-2MM	1	TRS-PHOTO-PNA1601M-2MM	PNA1601
□ TP1, TP2, TP3	TSP-P60R38	3	TP-60R38	
□ VRG1	VRG-LM78L05ACM-8-PIN-SOIC	1	SOIC-8PIN-150", LM78L05ACM"	

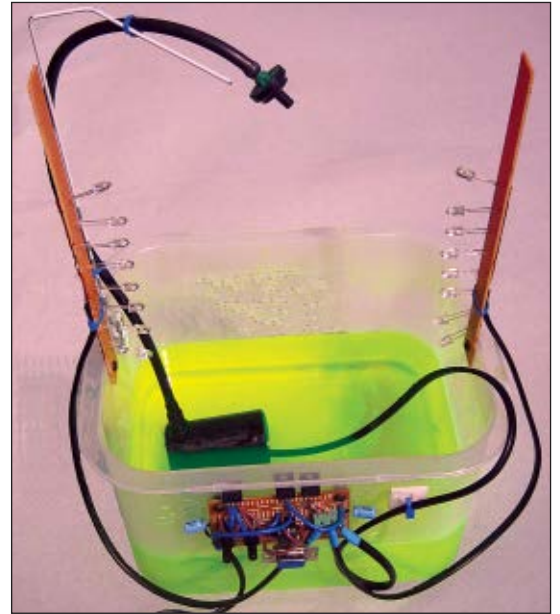
NOTE: Parts list for slot car circuit only. All the parts used for this application are shown. There are other equivalent parts that can be used, as well.

THE FREEZE FOUNTAIN

BY DAN DANKNICK

The appearance of stopping time can be fun – and truly messy!

An associate sent me a link to a cool video on the Internet that showed water droplets moving upward toward the spout. No, this wasn't on Art Bell's website and had nothing to do with Nikola Tesla, zero point energy, or the so-called Hutchison Effect. But it had everything to do with real science known as temporal aliasing a.k.a., the "stroboscopic effect." Wikipedia explains a machine employed toward this visual phenomena as "... an instrument used to make a cyclically moving object appear to be slow-moving, or stationary."



■ FIGURE 1. The completed Freeze Fountain.

Are you interested in building something both cool and interactive? Would you like to learn about microcontroller programming and basic electronics? If so, this is the project for you! (And if your 10-year-old isn't already writing Web 2.0 programs in Python, this would also make a great science fair project.)

What It Is!

The Freeze Fountain uses a submersible pump to emit a droplet stream of water with a dissolved fluorescent dye. It recirculates the flow into a catch bowl like a tabletop fountain (Figure 1). As the drops fall, ultraviolet LEDs continually strobe to excite the dye and convert UV light to something visible. When observed in a darkened room, groovy effects are exhibited (Figure 2). Manual controls for droplet and illumination rates allow you to interact with the device and have some fun. Set everything just right ... and you can freeze the droplet flow in place. Now that's cool!

As a software engineer, I am well heeled in fixing hardware problems through the magic of code. And as a science geek, I love things that make noise, have adjustments, and are messy. If you also feel that way, then this is a project you will love!

Gathering Parts

In any design, there is always some nuclear element that sets the base requirements. In this case, it was obtaining a submersible, low voltage DC powered pump. Most of the fountain pumps I located on the Internet were AC – either mains voltage or 12 VAC. They were cheap because they used the AC for commutation, but that made controlling their speed a complex problem. Eventually, I found a nice submersible DC pump designed for solar powered fountains. I had one directly shipped from China and it was excellent: only 200 mA at six volts and it came with a ton of piping accessories to tailor the emitted water stream. I also knew that for whatever gallon per minute (GPM) rate I chose, it would probably be wrong so my control logic would need to PWM the voltage to the pump to control it in some way. (Some submersible pumps use manual occlusion shutters to vary the flow and even before I ordered this pump, I knew that was a liability for readers not wanting to experience dyed fingertips.)

Enter the PICAXE-08M. I'd read about these for a while but had never seen a really good project done with one, so I ordered a chip just to play with. When coupled with the (free) Programming Editor for Windows, you have

a truly awesome digital controller for under \$5. The 08M has a hardware PWM that runs in the background (perfect to drive the pump), an eight-bit analog-to-digital converter (perfect for reading the control pots), and enough extra I/O to drive the UV LED arrays. It was “Game On” for the PICAXE.

The last difficult bit was locating some ultraviolet LEDs. Now, these are optically dangerous devices because they emit a wavelength of radiation that your eye is insensitive to, intensity wise. Look directly into a light bulb and your pupil closes to regulate the amount that hits your retina. That’s because it is “visible light.” But not with UV – an enormous amount of that “invisible” wavelength causes no such closure and could actually damage your retina (which is the only part of your central nervous system that can be directly imaged!) So NEVER look into a UV LED that is continuously on. The faint purple glow is NOT an indicator of the actual radiating power. In this project, the UV LED arrays are only pulsed for a fraction of a second so the radiated power is very low. But you should still avoid staring directly into them. Good ‘ol All Electronics stocked some UV LEDs with a 30 degree dispersion angle, emitting at 395 nm. As it turns out, this is ideal to excite the fluorescent dye in a typical yellow Sharpie marker.

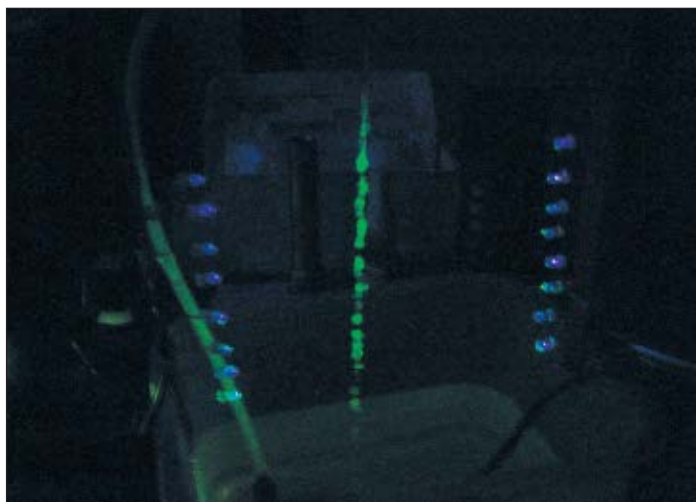
The remainder of the parts were dictated by the design and for whatever I didn’t have on the shelf I was able to purchase surplus. I chose an el cheapo 6 VDC wall wart to supply the power to my project because I figured that with a series diode, I could omit a 7805 linear voltage regulator (not to mention, the pump had a 6V motor in it). It turned out that the output of the ‘wart was closer to 10.5 VDC open circuit and rarely dipped below 8V even under load. (So much for believing the marked specifications!) I slapped in a 7805 and as I explain later, adjusted for everything else in software.

With everything on the bench, it was time to solder!

Circuit Description

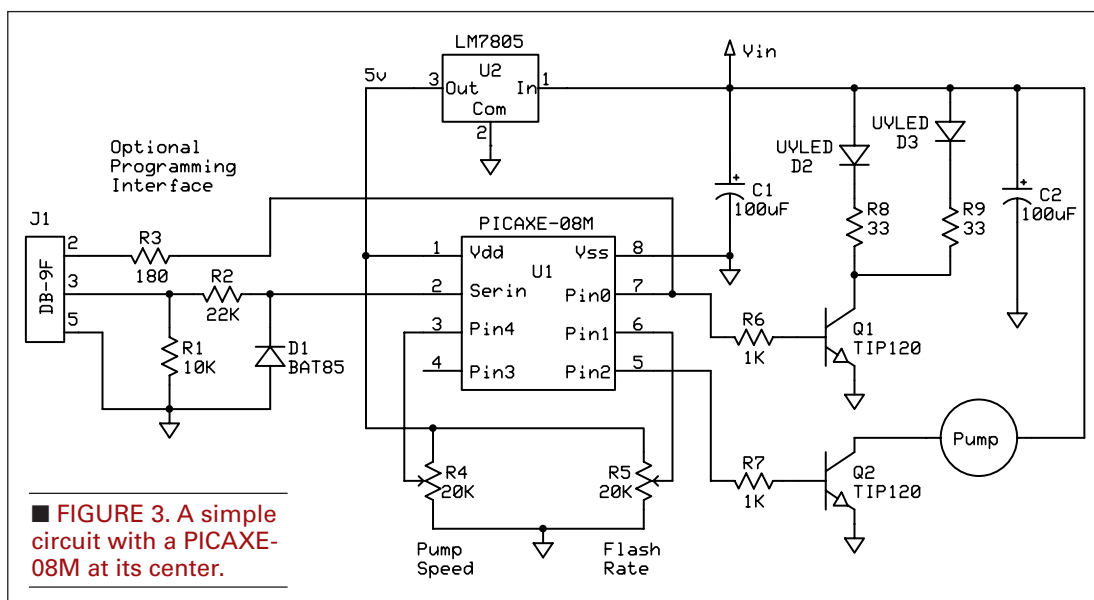
Refer to Figure 3 for the complete schematic. As you can see, it is pretty basic and is centered around a microcontroller. Yes, I know that at the end of this project some of you will (correctly) point out that a single 558 quad timer could probably get all of this done, as well. But that

■ **FIGURE 2. Dyed droplets of water caught in mid-air.**

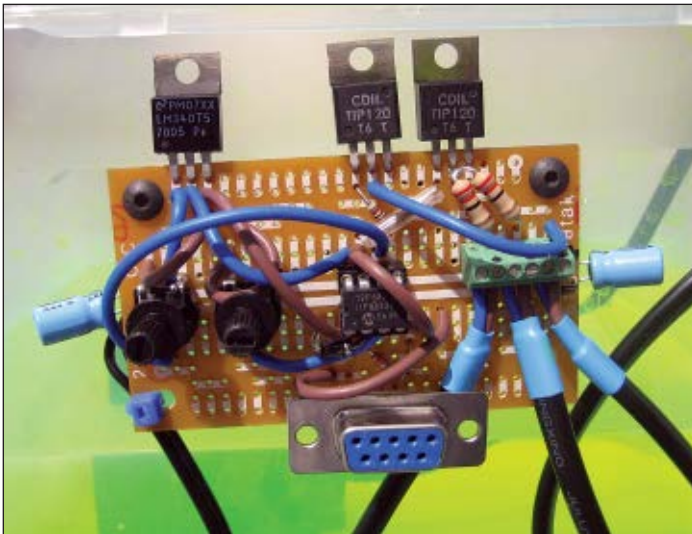


approach wouldn’t be as fun or teach all of the concepts I wanted to cover. And hey, it’s the digital age, man! Lighten up! Every circuit has an input, a processing unit, and an output. It is often helpful to break a new design down to these three functions to help identify the role of each component.

- **Input:** The two 20K potentiometers, R4-R5, serve this purpose. They are both configured as voltage dividers between V_{in} and ground, and apply a 0- V_{in} command to ADC inputs on the 08M. Their value is fairly irrelevant as anything about 5K is reasonable. But I found these surplus with knurled shafts so an additional knob wasn’t necessary.
- **Processing unit:** The reprogrammable digital controller, U1, is a PICAXE-08M. It runs a Basic program (explained later) to sample the inputs and update the drive signals to both the pump motor and the UV LED array.
- **Output:** The circuit function is expressed both by



■ **FIGURE 3. A simple circuit with a PICAXE-08M at its center.**



■ **FIGURE 4.** The prototype circuit with the reprogramming connector at bottom.

scenarios for your own setup online at www.quickar.com/noqbestledcalc.htm).

- I added C1-C2 as electron buffers to help the wall wart deal with current pulses to the pump motor and LED arrays. They really helped stabilize the system.

I built this circuit in about four hours on a small square of protoboard from RadioShack (Figure 4). You can see the voltage regulator on the power transistors at the top, the two input pots on the left, and the PICAXE in the middle. Connections to the LED arrays and pump motor are via the green screw terminal.

The Software Engine

Refer to Figure 5 which contains a cleaned up listing of the code that runs the Freeze Fountain. The complete source code is available on the *Nuts & Volts* website (www.nutsvolts.com) if you would like to modify it and reprogram the 08M (note that you will need to build the optional programming interface to do so). It is so short and simple, you could probably type it in faster than downloading it.

As I wrote above, I architected this project to teach some basic design skills in both electronics, as well as software. Let's look at how the program is structured and what it does.

Every conventional programming language is processed from top to bottom, and except for certain rules, from left to right on each line. PICAXE Basic is no different. The structure of our program is very simple: Set things up and then execute a loop that repeats forever — read the inputs, do some math, and drive the outputs.

The first five lines of code set things up. Line 1 tells the PICAXE Programming Editor what model chip it is working with and lines 3-5 define some variable storage space. We could just refer to the raw RAM-based bytes (b0, b1) and word (w1) in the code, but that makes it somewhat less readable. There is no penalty for giving

varying the power delivered to the water pump (and thus its flow), as well as the frequency of UV LED flashes. Two output pins of the 08M are buffered by Darlington transistors, Q1-Q2, to increase the current drive to their loads. This is a “common emitter” configuration, where the load is simply switched straight to ground. Resistors R6-R7 limit the base current into the Darlings. And as always, there are a few additional components:

- The optional programming interface is built from R1-R3, D1, and J1. I took this directly from Ron Hackett's website at www.jrhackett.net/cable.htm. If you plan to purchase a preprogrammed 08M to build this project, then you can ignore these parts completely.
- U2 makes certain there is a stable 5V supply to the 08M, as well as a divisible reference for the input pots.
- D2-D3 are each of the eight UVLED emitter arrays that rely on R8-R9 for current limiting. The LEDs I chose had a forward voltage drop of 3.7V and a maximum current of 20 mA. With eight LEDs in parallel on each side, the value of 33 ohms was indicated (you can play with what-if

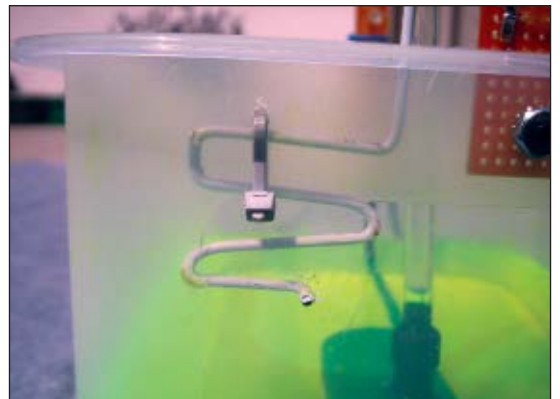
```

1  #picaxe 08M
2
3  symbol StrobeIn = b0
4  symbol MotorIn = b1
5  symbol work = w1
6
7  main:
8
9  ' Read the motor speed and strobe rate pots
10 readadc 4, MotorIn      ' 8 bit resolution is enough
11 readadc 1, StrobeIn     ' Again, 8 bit resolution is enough
12
13 ' Fire the UVLEDs
14 high 0                  ' Turn on the TIP120
15 pause 1                 ' Now turn it off
16 low 0
17
18 ' Adjust the power to the pump motor
19 work = MotorIn / 2 + 100 ' A rate between 40% and 91% at 16 kHz
20 pwmout 2, 62, work      ' according to the pwmout Wizard (cool!)
21
22 ' Calculate the delay time between UVLED strobes
23 work = StrobeIn / 2     ' Intermediate variable is 0..127
24 work = 140 - work       ' So, dark time delay is 13..140 ms
25 pause work              ' or 76..7 Hz
26
27 goto main

```

■ **FIGURE 5.** Code listing for the Freeze Fountain.

■ **FIGURE 6.** Securing the coat hanger wire to the catch basin.



them descriptive names.

Lines 10-11 read the two input pots and store their values in byte-wide variables for later recall. Because the pots are wired as voltage dividers from ground to 5V, they will return a value from 0 to 255.

Lines 14-16 strobe the UV LEDs by driving the pin 0 output high, pausing for a millisecond and then setting it low. When high, current flows into the base of Q1 and causes it to conduct. Current then flows down the LED arrays and they illuminate.

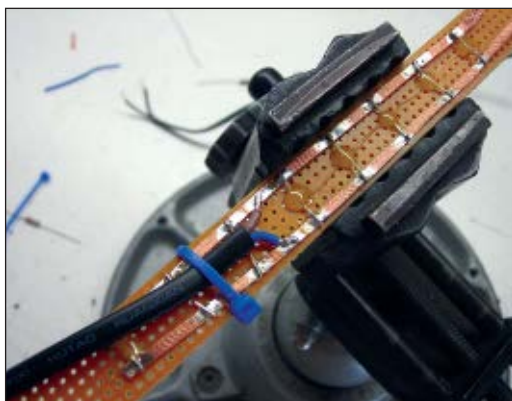
Line 19 computes an intermediate variable based on the ADC value before line 20 adjusts the PWM duty cycle to Q2 which drives the pump motor. The PICAXE Programming Editor contains some great “wizards” which are dialogs that help compute values for the esoteric internal settings of the part. I knew I wanted to vary the PWM duty cycle of the pump from between about 40% and 91%, so it set me up with the answer. Note that a free running, hardware PWM unit is attached to pin 2 of the 08M and will keep doing its thing independent of what foreground Basic program is running. (This is the sort of thing you look for in μ Cs when you’re trying to solve real-time requirements on the cheap.)

For the pump I selected, a 16 kHz PWM rate appeared to work the best. If you choose a different pump, then you may need to adjust the frequency (and the range of duty cycles, as well).

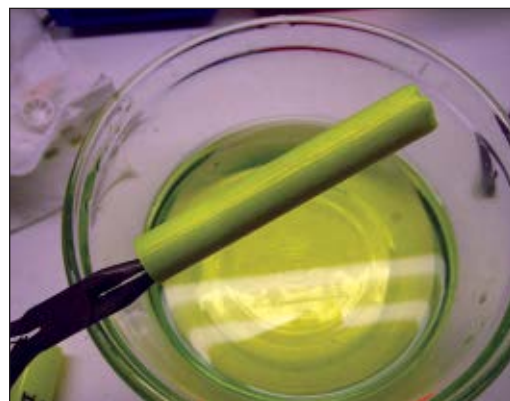
Most microcontrollers power up with all I/O pins set as inputs, not outputs. If you wonder why, consider this: What output value would *always* be safe to express to the outside world? Answer: There is no value. So the very nature of the pin cannot be an output unless safely defined in the program. The “high,” “low,” and “pwmout” commands of the 08M automatically convert their targeted I/O pins to “output mode” so they can operate correctly.

Lines 23-25 compute and execute a delay time based on the strobe input potentiometer. This can range from around 7 to 76 Hz.

And finally, line 27 simply completes the endless loop of sampling the inputs



■ FIGURE 7. Desoldering braid connects all of the LEDs in parallel.



■ FIGURE 8. Removing the radioactive core from its protective container.

and adjusting the outputs; 90% of embedded controllers operate in this manner so if it seems simple then hey, you now understand the monotony of process computers!

The Environment

The wet enclosure was a Sterilite model 1892 CD storage box that I found at Wal-Mart for \$3. To it were attached four things: the main circuit, two UV LED

PARTS LIST

ITEM	DESCRIPTION
(All resistors are 1/6th or 1/8th watt unless noted)	
□ R1	10K
□ R2	22K
□ R3	180 ohms
□ R4,R5	20K linear taper potentiometer
□ R6,R7	1K
□ R8,R9	33 ohm, 1/2 W
□ C1,C2	100 μ F, 16V electrolytic
□ D1	BAT85
□ D2,D3	Each are eight UV LED arrays (i.e., the ULED-2 from www.allelectronics.com)
□ Q1,Q2	TIP120 Darlington
□ U1	PICAXE-08M microcontroller (www.jrhackett.net)
□ U2	LM7805 linear regulator
□ J1	DB-9F (female DB-9 for programming)
□ Pump	6 VDC submersible water pump (i.e., the MP200 from www.solarkey.com)
□ Wall wart	6VDC at 500 mA or more (i.e., the CES-301 from www.action-electronics.com)
□ Fluorescent dye	A gutted yellow highlighter will work fine (see text)
□ Tubing, emitter	1/4" drip line which fits the port adapter included with the SolarKey pump, 2 GPH dripper Bowl to build it all in (Sterilite 1892, etc.), eight pin IC socket, flowers for the wife to compensate for the mess you will make
□ Misc.	

Both the preprogrammed PICAXE-08M, as well as a complete kit of parts are available from the *Nuts & Volts* online store at www.nutsvolts.com.

standards, and a length of metal coat hanger to blouse the dyed water hose.

I was fairly cavalier in attaching all of these bits to the plastic box, using #6 machine screws and zip ties. These served to mount the main circuit and the LED standards while the pump sported four suction cups on its base. I was able to keep it from sliding around after cleaning the bottom of the box with denatured alcohol.

The pump I bought came with a pile of extensions and adapters. I found that the one that converted the output to 1/4" OD plastic hose was the best. Not surprisingly some drip irrigation parts worked the best for the hose and the emitter (a 2 GPH dripper.) As you can see in Figure 1, I simply zip-tied it along to the coat hanger. Bending the coat hanger wire to attach it to the basin was a trick

(Figure 6). The final height and orientation is unimportant as it can be compensated with by the pump speed control.

The UV LED standards were built quite easily using some more protoboard and ChemWick desoldering braid. I placed the LEDs every 0.6" and soldered them in parallel on the back of the protoboard (Figure 7). A dab of hot melt glue on the back secured the leads enough to allow refocusing. The pump came with 15 feet of cable so I chopped it up to wire the standards and all of the components on the main controller board.

The final — and most messy — part of the project is creating the dyed water. It turns out that a yellow Sharpie Accent highlighter contains everything you need. Simply pop out the end cap, extract the dye-soaked core (Figure 8), and wring it out in the water of your catch basin. If you're building this project with your kids, you will want to hand this off to them as it's the most messy. In my prototype, I found that two highlighters contained plenty of dye to color a quart of water. And they only cost about 25 cents apiece. (When you're done, drain the

The PCBs and/or a complete kit for this project can be purchased through the *Nuts & Volts* Webstore at www.nutsvolts.com or call our order line at 800-783-4624.

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basin of dyed water into a two quart soda bottle to save for later.)

Operating the Waterworks

Once you get everything built, it's time to have some fun! You don't need to operate the Freeze Fountain in a completely dark room which is helpful as you learn the controls.

First adjust the pump speed to obtain a steady dripping. Once that is stable, adjust the strobe rate for some neat effects like freezing a droplet in mid-air or even giving it the appearance of moving upward! Splashes are also fun to visualize on the surface of the water as well as objects inserted into the catch basin.

Conclusion

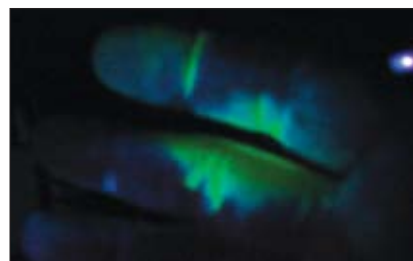
This project has a little of everything in it! My design was intended to teach you how to craft a reprogrammable

■ **FIGURE 9.** I'll wear gloves next time.

system that can be easily adapted to varying component tolerances. I also like devices that have adjustments and outputs with a myriad of combinations. This is a good project to build with your kids and pull out at family gatherings to stimulate a discussion of science. Just don't blame me if you end up with fluorescent fingers (Figure 9)! **NV**

If you build a freeze fountain, be sure to send a video clip or photos of your setup to editor@nutsvolts.com to share with other readers on our website. Playing with the controls and inserting objects into the drip stream can make some interesting effects.

Dan Danknick is a firmware engineer in southern CA and former technical editor of this magazine. He welcomes your comments and can be reached via dan@teamdelta.com.



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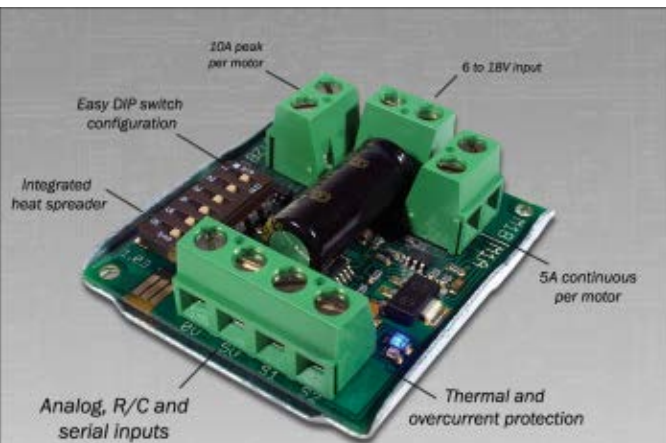
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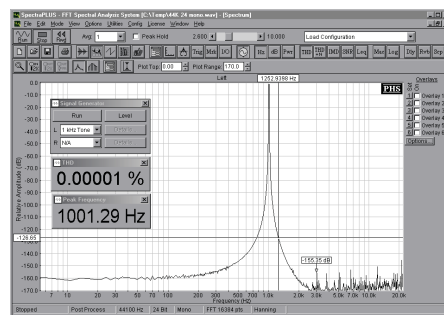
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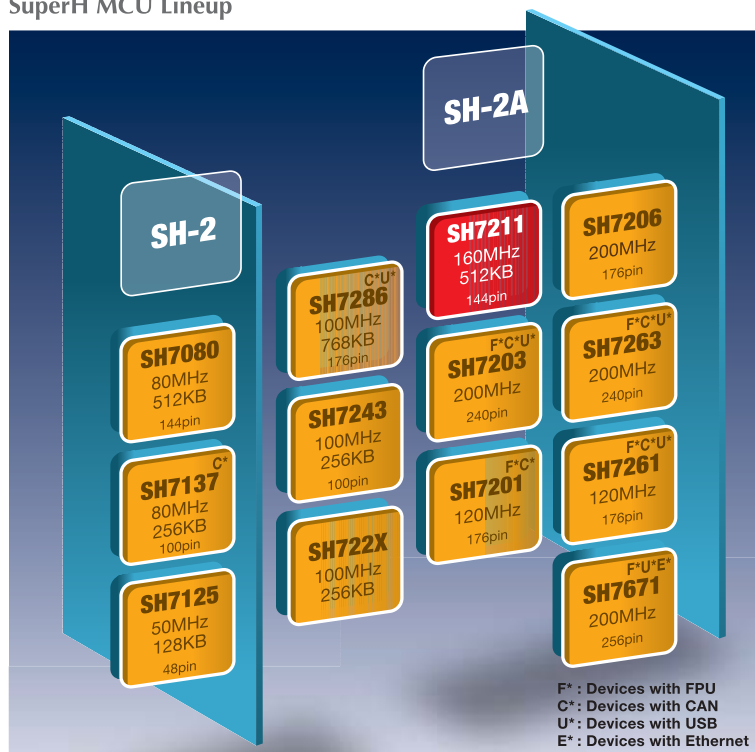
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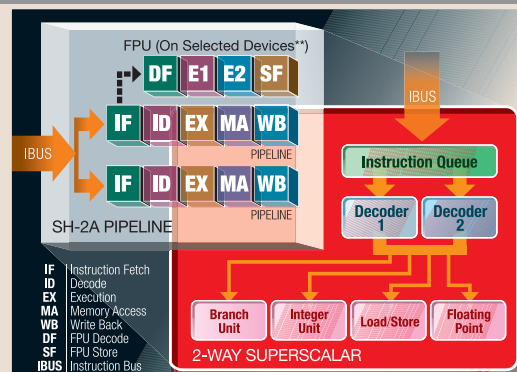
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by Evan Woolley

Don't let a few crazy looking symbols prevent you from completing a project!

“HOW TO” BASICS

To experienced tinkerers and electronics gurus, they can be a clear treasure map that leads straight to the intellectual pot of gold that awaits at the end of a project. To novices, they can be a cryptic combination of symbols that might as well be a part of the Da Vinci code. I'm talking about schematics — those wonderfully symbolic diagrams that are supposed to help intrepid tinkerers wire up circuits and populate printed circuit boards (PCBs).

Reading schematics is an important skill for a builder hobbyist, because so many projects involve DIY electronics in some capacity. It might be populating the PCB of a kit that sports the label “some assembly required,” it might be the addition of a sensor module to a finished robot, or it might be the secret to cracking open and hacking a device that keeps its electronics hidden, but schematics always pop up when pursuing electronics projects. And despite their apparent complexity, schematics are really nothing to be afraid of after a proper introduction.

Modern Hieroglyphics

Schematics are built upon a veritable alphabet of symbols that correspond to different electronic bits, and becoming familiar with this lexicon is the first step in becoming schematic literate. You will also notice when you look at a parts list for a circuit, there are values for the various parts that are important to pay attention to. Most of the value names come from the discoverer of the particular electronic function that the component deals with. The three most basic components that you are likely to find on a schematic are resistors, capacitors,

and inductors. A resistor and its corresponding symbol are shown in Figure 1. Resistors are simple bits that absorb voltage (and, as a result, power). Resistors are used to protect other, more sensitive parts from excessive voltage or current. When you look closely at a common resistor, small colored rings are visible on the body that correspond to the value of that component, which for a resistor is given in ohms (Ω). A resistor with an arrow pointing to it or through it is actually a variable resistor, also known as a potentiometer. Resistors are the main ingredients to some useful circuits, but there are two other components you will need before you can make a circuit — a voltage source and a ground.

A voltage source can either be direct voltage (like from a battery) as in Figure 2, or alternating (like what you get from a wall plug), as in Figure 3. A voltage source creates a potential difference in the circuit that motivates the flow of an electric current. To close the loop of the circuit, there needs to be a ground, as shown in Figure 4. The ground can come in two flavors: the chassis ground (which is the main global ground) and the signal ground (a local ground for sensors and the like). It is not uncommon for schematics to show multiple and both types of grounds.

Even with just a voltage source, ground, and resistors, you can make some useful circuits. Perhaps the most useful is the voltage divider, given in Figure 5. The voltage divider is simply a set of resistors in series, and this setup can be used to effectively scale down a voltage for whatever load is connected in parallel to a certain resistor.

But alas, electronics projects are not always so simple as a bunch of resistors. Capacitors (Figure 6) and inductors (Figure 7) are also sure to make an appearance.

Capacitors are a set of metal plates that store electric charge, and inductors are metal coils that create an electromotive force when they experience a current that affects their magnetic field. The capacitor shown is in the ceramic type casing, and capacitors also commonly appear as metallic cylinders. The inductor shown is more of a model, since I didn't have one handy. A wire coiled around a ferrous cylinder is a rudimentary model of an

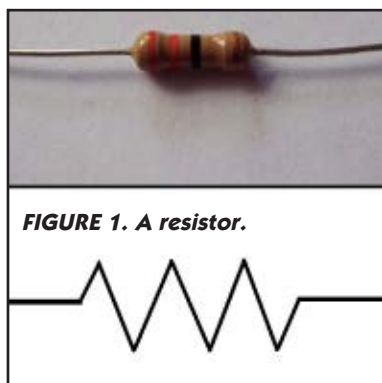


FIGURE 1. A resistor.

inductor, but the real deal electronic bits are normally encased in cylinders.

Sometimes the cylindrical capacitors can be hard to tell apart from the inductors, but the surefire way to tell them apart is to see what units appear on the casing. Capacitance is given in farads (F) and inductance is given in henrys (H). Thankfully, there is no potential for confusion when it comes to the schematic symbols.

Circuits with resistors, inductors, and capacitors are referred to as RLC circuits, and they can manifest themselves in a variety of useful bits. A low pass filter, for example, can be used to attenuate (cancel out) high frequency signals and is given in Figure 8.

Another circuit element very often seen populating PCBs is the diode, shown in Figure 9. A diode essentially acts as a one-way valve for current. What the diode does to a current (allowing it to flow in only one direction) is called rectification, so diodes are also occasionally called rectifiers. One of the most common flavors of the diode seen in projects is the Light Emitting Diode, or LED. The symbol for an LED looks exactly like that for the regular diode, but the LED also has two arrows pointing away from the diode at an angle. Arrows pointing towards the diode symbol would indicate a photodiode.

The switch (shown in Figure 10) is another common inhabitant of the schematic. A switch opens and closes all or part of a circuit, allowing or disallowing current to flow to that section. The switch shown in Figure 10 is a normally open pushbutton switch. Switches also come in a variety of flavors, like a normally closed pushbutton switch, the Single Pole Single Throw (SPST) switch (like an on/off switch), the Single Pole Double Throw switch (SPDT), and many others.

Another useful tool is the operational amplifier, which has inner workings that include resistors and dependent sources, but is easily represented in Figure 11. Operational amplifiers — or op-amps for short — perform a variety of tasks such as amplifying (increase) voltage, inverting (change sign) voltage, summing voltages from multiple sources, and many more, but they will not be seen on their own in schematics for electronics projects. Op-amps are usually included as a part of Integrated Circuits, or ICs.

ICs are those little four to eight (or more) legged black boxes, as shown in Figure 12. The setup in Figure 12 is the Dual In-Line Package (DIP), which in my experience is one often favored for robotics projects because it is compact and easy to solder. ICs come in other packages, with one of the more common packages being a vertical, black rectangular prism with three thick, flat legs and a metallic



FIGURE 2. Direct voltage source.



FIGURE 6. A capacitor.

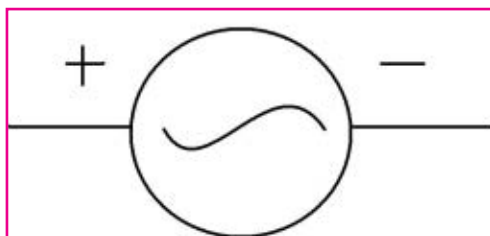


FIGURE 3. Alternating voltage source.

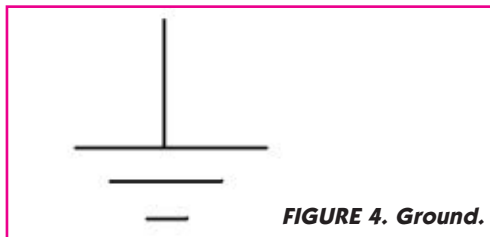


FIGURE 4. Ground.

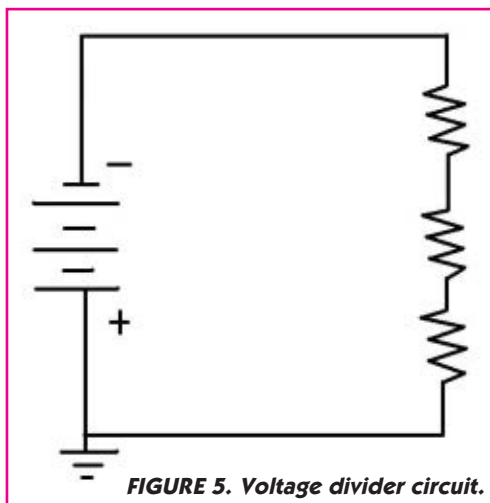
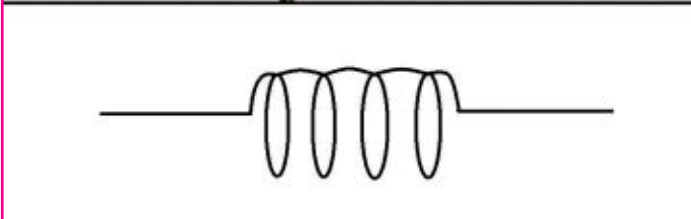
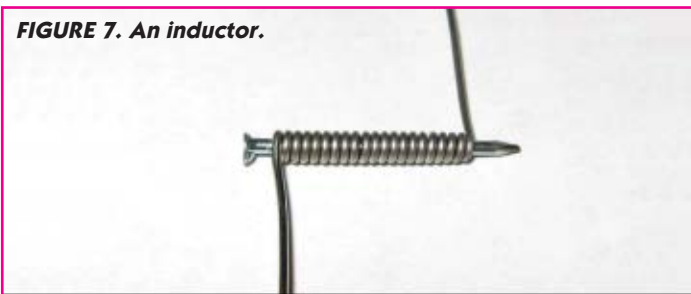


FIGURE 5. Voltage divider circuit.

FIGURE 7. An inductor.



tab coming off the top that acts as a heatsink.

The term “integrated circuit” is an umbrella phrase that includes everything from sophisticated logic gates to microcontrollers, but another specific type of IC that pops up all the time is the transistor, shown in Figure 13. Transistors can amplify and rectify signals, and they come in a variety of flavors like NPN, PNP, N-JFET, and P-MOSFET. Transistors, like most ICs, actually contain a whole web of

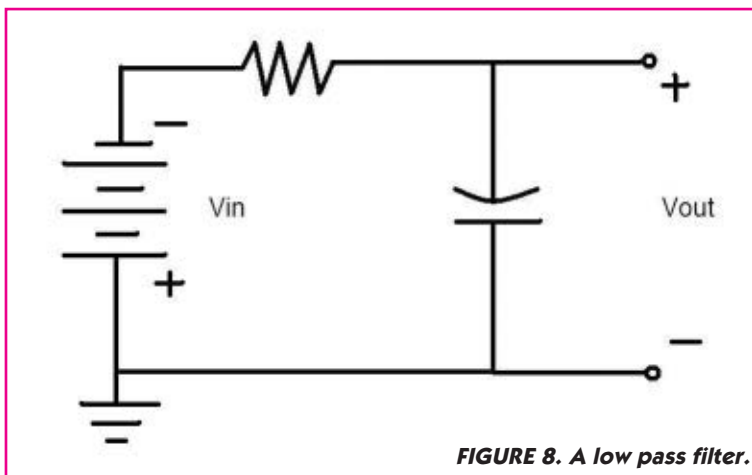


FIGURE 8. A low pass filter.

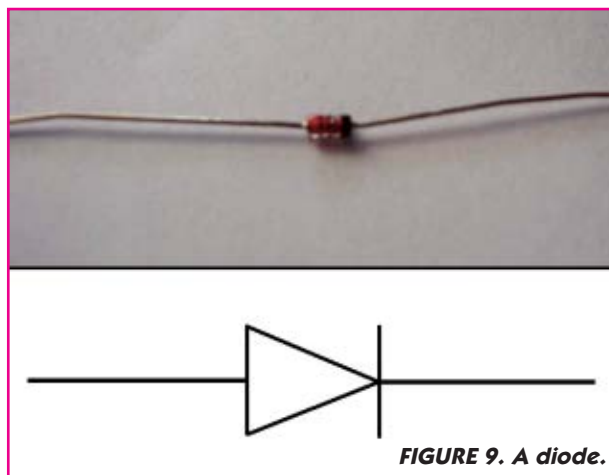


FIGURE 9. A diode.

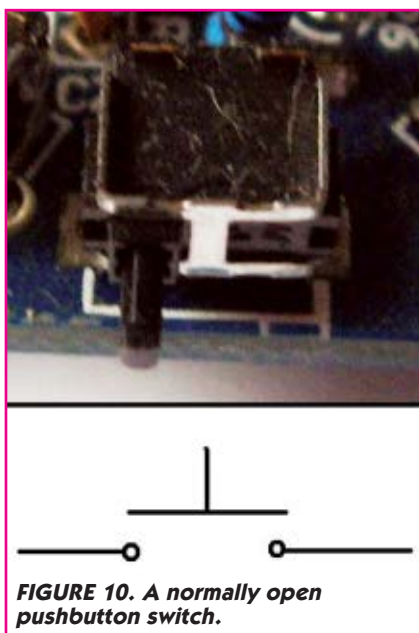


FIGURE 10. A normally open pushbutton switch.

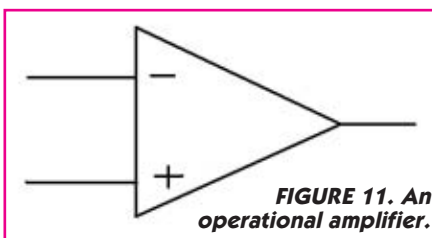


FIGURE 11. An operational amplifier.

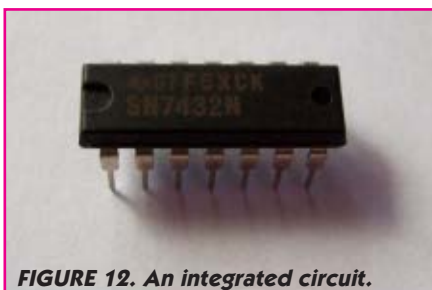


FIGURE 12. An integrated circuit.

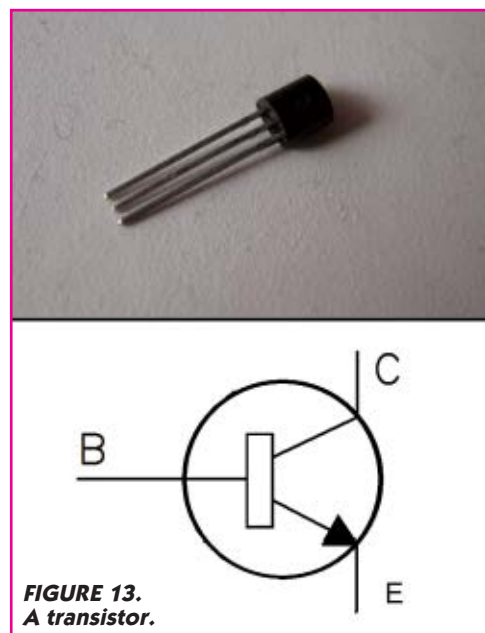
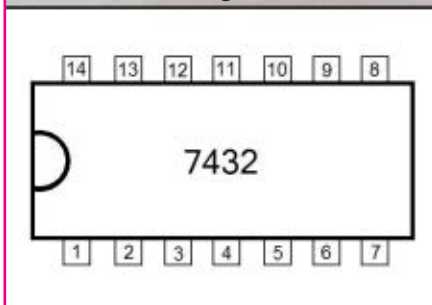


FIGURE 13. A transistor.

basic circuit components, but thankfully tinkerers do not need to completely understand the complex subtleties of their inner workings to use them properly. Just think of them as a fast electronic switch.

Putting the Pieces Together

After being able to identify and understand the basic symbols, the next step in learning the language of schematics is to know how everything fits together. Everything is connected by wires, which are simply represented by lines. In schematics, wires are assumed to have no resistance, and the wires can be stretched, shrunk, and take crazy paths with no effect on the circuit. (Okay, that is a bit of a generalization since some more sensitive circuits are adversely affected by wire routing and length.) Just keep your wiring tidy and as short as possible, and your circuit will perform as designed.

Most schematics try to show the most efficient path from point A to point B, so the web of wires stays pretty clear. One important note is the distinction between wire

by one solid wire and one broken wire that avoid a point of intersection (but this may not always be the case).

A good number of schematics find it too much of a bother to have the one broken line, so they will simply show wires crossing over each other like two lines that do physically intersect, but do not have a dot at the intersection. Some schematics show one of the wires at a crossing with a half circle going over the other wire to indicate there is no connection. Complicated schematics will often have many more crossovers than junctions, so just be careful and don't be confused by crisscrossing wires.

Another fundamental is polarity. Many components like resistors and some capacitors could care less about what orientation you place them in the circuit, but sometimes polarity does matter, and ignoring it can be disastrous. Thankfully, schematics are usually designed to make things

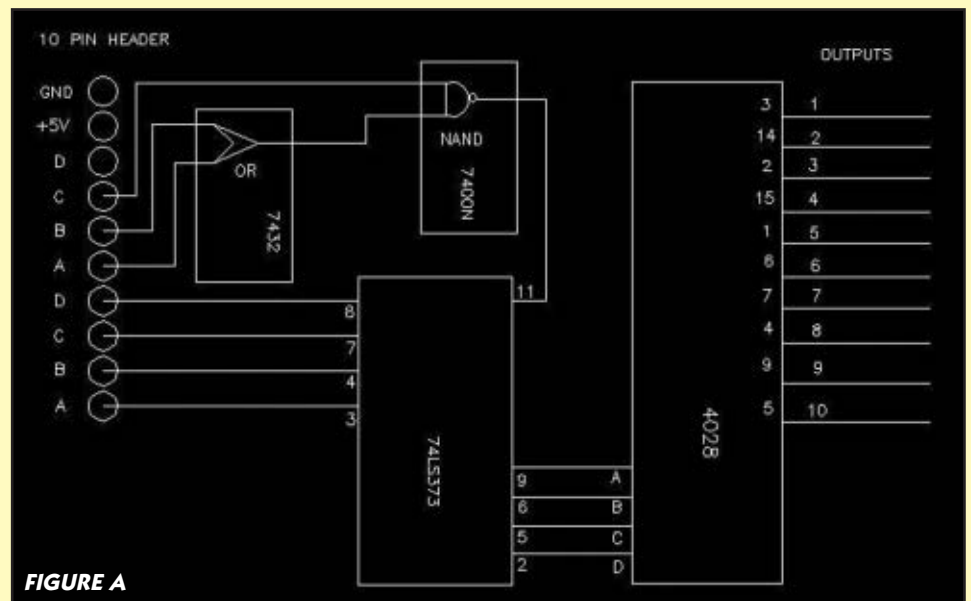
Pop Quiz

Let's look at a simple schematic to see if we can figure out what is going on. Figure A shows the schematic for an integrator circuit for a voice recognition module that we worked on a few months ago. As you may have noticed, the integrator circuit seems strangely devoid of a lot of the symbols we just took time to learn about. In the case of this circuit — which cannot function without being connected between the voice recognition module and the external device you want to control with it — things like the power and ground are taken to be part of the 10-pin header (which will eventually lead to those things). A 10-pin header is

a type of connector, and the ground pin is designated as GND; the power pin is designated by +5V. The only other inhabitants of the schematic are four ICs. The legs are not explicitly shown in the diagram, but the numbers do correspond to specific legs on each IC. Let's go through each IC to see if we can figure out what they're doing.

The first IC we come across is the 7432; the number refers to the part number of the IC, which is what you'll reference when leafing through a catalog or pawing through the drawers at a local electronics store. As you can see, this IC doesn't have a lot connecting to it because we simply needed it for the OR gate on the inside. A number of different ICs could have been used instead of this one, and even on this particular one we could have attached the wires to different legs than the ones that we chose. All that matters is that the correct wires from the 10-pin header connect to the proper legs of the OR gate. On the spec sheet for the IC, it showed the inside of the IC (in this case, a bunch of OR gates) and it labeled each leg and its corresponding one on the OR gate.

The next IC is the 7400N, which is simply used for the NAND logic gate. The process of selecting and wiring up



this IC is identical to that of its OR gate cousin. The 7400N is an IC filled with a bunch of NAND gates.

The other two ICs are a bit more sophisticated and a bit more integral to the functioning of the circuit. The 74LS373 is actually a microcontroller, so we haven't shown the complicated inner workings of the black box. (It's actually an octal D-type flip-flop with a three stage output! This is why you only need to know the number and where it goes in the circuit and not necessarily all of the details.)

Normally, schematics won't show you the internal logic gates like we have for the other ICs; the diagram will only represent ICs as enigmatic rectangles. To wire up the circuit from the schematic, a tinkerer does not need to know what exactly goes on inside an IC; they just need to know how to identify which leg is which and which wire connects to it. Of course, it is nice to have a concept of what the function of the IC is, and if you haven't been around electronics long enough to identify what an IC does simply by its part number (I certainly haven't), then the spec sheet is sure to be illuminating. The 4028 is also a microcontroller, and wiring it up simply demands a careful accounting of which leg is which.

as easy as possible for the reader, and polarity will be clearly indicated by a plus sign for the positive side and a minus sign for the negative side. On actual components, the positive leg may be identified in a number of ways. Sometimes the positive leg will be longer than the others, or the base of the leg will be emblazoned with a dot. In the case of ICs, the semi-circular cutout at one of the ends is used to indicate orientation, and the physical component should be placed to match the orientation indicated by the corresponding semi-circle on the schematic.

One of the most important things to know when using ICs in circuits is which leg is which. Often on schematics, wires that feed into ICs have their destination labeled by only the leg number, and many times the legs will be arranged in the most convenient way for drawing the schematic. This means that the placement of the legs on the diagram might not necessarily match their physical locations on the DIP. Thankfully, the numbering system for

IC legs is pretty straightforward. The aforementioned semi-circular cutout represents the "top" of the IC. If the top of the DIP is facing left, the first half of the legs number from one to the halfway number from left to right on the bottom side. The second half of the legs number up until the final number from right to left on the top side of the DIP. The legs of the DIP shown in Figure 12 are numbered accordingly.

An overarching law of circuits and schematics is that everything needs to have power and everything needs to be grounded. If the ground is not labeled by one of the aforementioned symbols, it may then be labeled by text (GROUND or GND). Every single component does not need to be connected to power or ground individually, but do have to make it there somehow. Some components demand their own power and ground, however. Multi-legged ICs will often need to be connected to power sources and ground even if the components connected to

them make it back to power and ground, themselves. The legs on ICs may be labeled to correspond to such cryptic things as Vin, Vout, Vcc, V5+, or V5-, but the bits that need to connect to these legs will be clearly labeled as such.

One thing to note is that a power source may not always be present in a schematic you're looking at, especially if the circuit shown is just a part of something bigger or a dependent part of a whole. In those cases, the wires will likely terminate at some sort of plug or connector that will eventually lead to power and ground.

Often, projects will demand the placement of certain logic gates, like NAND and OR gates. The easiest way to incorporate gates may be to use an IC that isn't specifically called for, but still contains the necessary gates. The spec sheets on ICs will show the inner workings of the mysterious black boxes, and the legs of logic gates and other internal bits will clearly correspond to certain legs on the IC. NAND, OR, Huh? Here is a very brief explanation of terminology. AND and OR mean exactly that — this AND that will happen; this OR that will happen. NAND means Not AND, NOR means Not OR. When you look at the circuit and what it is supposed to do, the functioning of the specific logic gate should become apparent.

There are also many other electronic bits that can populate schematics; everything from speakers to compasses to infrared receivers. While there are still symbols for other bits outside of the basic ones I've covered, many of the more novel additions will be represented as simple boxes, circles, or other basic shape with some kind of identifying label. These basics, however, should be able to get you through most schematics.

Connect the Dots

Schematics are often much more complex than the tame voltage divider or the only mildly feral integrator circuit, but even a novice electronics tinkerer can figure out what's going on after becoming familiar with the symbolic alphabet. On their own, resistors, diodes, and even DIP ICs become manageable, so a mess of wires and a seemingly overpopulated PCB shouldn't be insurmountable. A careful accounting of what connects to what, polarity, and the leg numbers of ICs should be all you need to follow even the most convoluted schematic. Don't be intimidated by crossing wires and DIPs that seem like millipedes — carefully following the wires like a strange game of connect-the-dots should help you to pull through. **NV**

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By Jan Axelson ACCESS SERIAL PORTS WITH PICBASIC



Last month, I showed how to use Visual Basic .NET to transfer data via a PC's serial ports, including USB virtual COM ports. I described a Visual Basic application that sends commands and receives responses from a device connected via a serial port. This month, I'll show a companion PICBASIC PRO program for a PIC microcontroller. The program detects received commands, takes requested actions, and sends responses. I'll also show how to use an RS-422 interface to create serial links as long as 4,000 feet.

Serial Port Hardware

I wrote the code in this article for a PIC18F4520 microcontroller. Like many PICs, the 4520 has a built-in serial port. The chip's EUSART manages serial communications and supports an asynchronous mode that is compatible with serial ports on PCs. PORTC.6 (TX) is the serial output, and PORTC.7 (RX) is the serial input.

I ran the code on Microchip's PICDEM 2 Plus development board. On the board, the PIC's serial port interfaces to a MAX3232 chip, which converts between the PIC's 5V signals and RS-232 voltages. The board has a nine-pin female D-sub connector for the RS-232 cable.

Most RS-232 serial ports on PCs have male nine-pin D-sub. USB/RS-232 adapters are also available with these connectors. To connect a PICDEM 2 Plus board to a serial port on a PC, use a straight-across cable, not a null-modem cable or adapter, which swaps the lines in the cable. If in doubt, use an ohmmeter. If you probe pin 2 of each connector on the cable, and the resistance measures close to zero, you have a straight through cable.

Why use a serial port and not USB? Serial ports are a good choice when you want to keep things simple and inexpensive. The program code to access a serial port is less complex than what's required to communicate via USB. Plus, the number of microcontrollers with embedded serial ports is much greater than those with embedded USB controllers.

Accessing the Port

Listing 1 is PICBASIC code that configures the PIC's serial port and runs the main program loop. (The complete code plus a Visual Basic .NET project to use with it are

```
' Define the oscillator's frequency in MHz.
' The default = 4.

define OSC 4

' Enable the port and receiver.

define HSER_RCSTA 90h

' Enable the transmitter and set BRGH = 1.

define HSER_TXSTA 24h

' Set the bit rate.

define HSER_BAUD 1200

' Clear serial-port overflow errors automatically.

define HSER_CLROERR

serial_in      var BYTE
received_text  var BYTE[5]

' PORTB.1 is an output that drives an LED.

TRISB.1 = 0

' Enable unmasked peripheral interrupts

INTCON = %11000000

' Enable the serial receive interrupt

PIE1 = %00100000

on interrupt goto receive_serial_data

' The main program loop.

loop:

' Perform additional actions here.

goto loop

end
```

LISTING 1. A series of registers configures the serial port and the serial interrupt.

available from **www.nutsvolts.com** and my website, **www.Lvr.com**)

In the PIC, several registers enable the port, set the bit rate, and store received data and data to

transmit. The chip's datasheet details the functions of the register bits.

The example program contains an endless do-nothing loop. A real-world application can perform any needed actions in the loop. For example, a monitoring device can read sensor data, or a motor-control device can send control signals to the motors.

Listing 2 is an interrupt service routine (ISR) for the serial port's receive interrupt. The ISR runs when a new byte has arrived at the serial port. On a framing error, the routine reads the data to clear the error but otherwise ignores the data. Causes for framing errors include bit rates that don't match and a noisy line.

On receiving data without an error, an hserin statement stores incoming data until receiving a line feed (LF) code of 0Ah, receiving five bytes, or waiting one second — whichever occurs first. On a timeout, the ISR exits with no further action. On receiving a LF or five bytes, the ISR calls the routine in Listing 3. The routine checks to see if the serial port received a valid command.

The routine understands two commands: "L11" and "L10." On receiving "L11," the routine sets PORTB.0 = 1 to turn on LED RB1 on the PICDEM 2 Plus board. The device then sends an acknowledgment consisting of the character "1" followed by a LF. On receiving "L10," the routine sets PORTB.1 = 1 to turn off LED RB1 and sends the character "0" followed by a LF.

A remote computer that sends a command and receives either "0" or "1" followed by a LF can assume the command was received and carried out.

You can test this code with the Visual Basic .NET example presented last time, or you can type commands and view responses in a terminal-emulator utility such as Hyperterminal. Some terminal emulators send a carriage return (CR) code (0Dh) preceding the LF at the end of each line. The PICBASIC code ignores a received CR before the LF.

Preventing Overflows

On the PIC18F4520, the serial port's input buffer can hold only two received bytes. If the buffer is full and a third byte arrives before the program code has retrieved at least one of the bytes from the buffer, the new byte has nowhere to go and is dropped.

Using an ISR helps the program respond quickly to received data. When a byte arrives at the serial port, the code in the ISR runs as soon as the currently executing PICBASIC statement completes.

In the ISR, the hserin statement waits to receive all of the bytes in a command, storing the bytes as they

```
disable

receive_serial_data:

    if (RCSTA.2 = 1) then
        ' A framing error occurred.
        ' Read RCREG to clear the error but don't use the data.

        hserin [serial_in]

    else
        ' No framing error occurred. Wait for a LF code
        ' (0Ah), 5 characters, or a timeout.

        hserin 1000, continue, [STR received_text\5\%a]

        gosub respond_to_command

        continue:

    endif

resume
enable
```

LISTING 2. The interrupt service routine stores received data.

```
respond_to_command:

    ' Check for defined commands.

    if (received_text[0] = "L") AND (received_text[1] = "1") then

        ' The command begins with "L1".

        select case received_text[2]

            case "1"

                ' Turn on the LED.

                high PORTB.1

                ' Send a response ending in a LF.

                hserout ["1",10]

            case "0"

                ' Turn off the LED.

                low PORTB.1

                ' Send a response ending in a LF.

                hserout ["0",10]

            case else

        end select

    endif

return
```

LISTING 3. The device responds to two commands.

arrive. Waiting for the entire command prevents buffer overflows. The penalty is that the code can't do anything else while waiting for the rest of the command to arrive.

Because the currently executing statement must finish before the ISR runs, avoid statements that take a long time to execute, such as pauses with long delays. If you need faster response, PICBASIC supports using ISRs written in assembly code. Another way to allow more time to retrieve received data is to use a slower bit rate, which results in more time between received bytes.

Some systems use hardware flow control — also called handshaking — to prevent missed data. RS-232 has defined hardware flow-control signals. On a PC's port, Request to Send (RTS) is an output, and Clear to Send (CTS) is an input.

On a PIC, hardware flow control requires two otherwise unused port bits and an additional RS-232 driver and receiver. The MAX3232 on the PICDEM2 Plus board has a spare driver and receiver. You can solder jumper-wire connections to these (Figure 1), but the chip is surface-mount, so soldering can be tricky. Another option is to solder another MAX3232 or similar interface chip in a through-hole package to the board's prototyping area and wire the needed connections to the chip.

In Figure 1, note that the RS-232 signals are named from the perspective of the remote PC. The PIC's TX output controls RS-232's RX signal, which is an input on the PC, and RS-232's TX signal, which is an output on the PC, controls the PIC's RX input.

Some development boards wire CTS and RTS together at the RS-232 connector. If you need to use hardware flow control, check your board's schematic and cut any unwanted connections.

In a PIC using hardware flow control, program code must bring the CTS port bit high when the port isn't ready to receive data. The RS-232 driver inverts the signal, so on the cable, CTS is a negative voltage. At a PC that wants to send data to the PIC, an RS-232 interface chip re-inverts

CTS, resulting in a logic high output. The PC must detect the state of CTS and stop sending data when the output is logic high.

When sending data using hardware flow control, program code must detect the state of RTS and send data only when RTS is logic low at the PIC (and thus a positive voltage on the RS-232 cable). PC software uses large buffers, so when communicating with a PC, the PIC isn't likely to need to monitor RTS.

PICBASIC PRO and other PIC compilers can also create software serial ports using any spare port pins. Instead of using the chip's hardware EUSART, the compiler controls communications with the help of an on-chip timer. For software ports, PICBASIC's `serin2` statement can name a flow-control output bit that toggles automatically as needed to prevent overflows, and `serout2` can name a flow-control input bit. Software ports can't use the serial port's hardware interrupt, however.

Two other RS-232 signals are DTR and DSR. Some PC software requires DSR to be asserted (positive RS-232 voltage) to signify the device is powered. The PICDEM2 Plus board connects DTR to DSR on the RS-232 connector so at the remote computer, the DSR input always follows the DTR output.

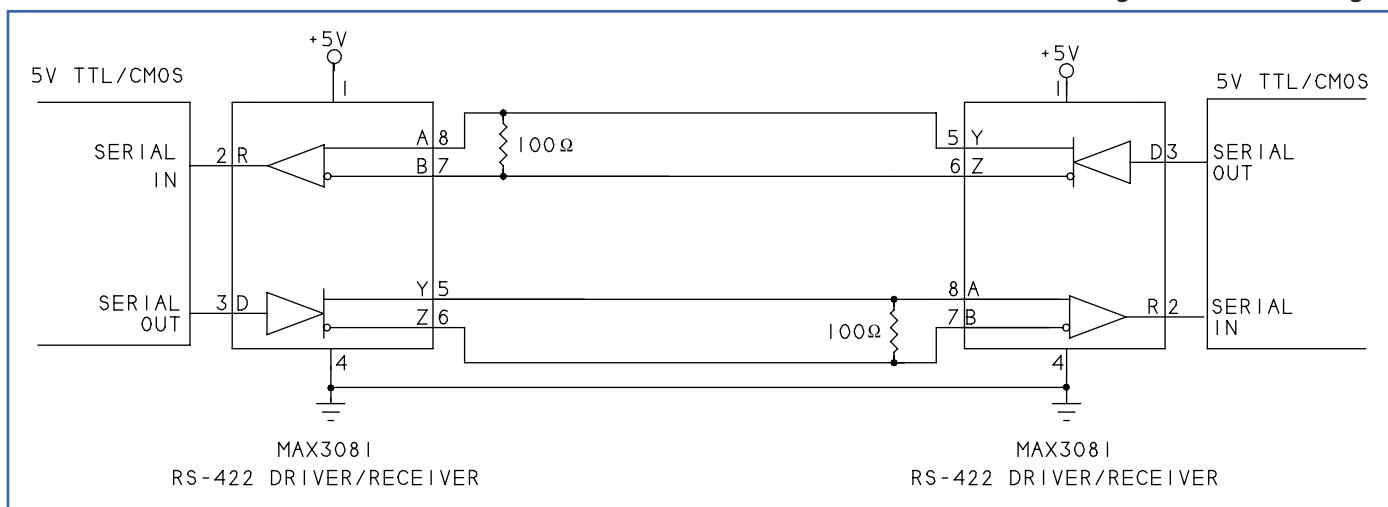
To enable using DTR and DSR for flow control or other uses, cut the circuit board trace that connects these signals together. Add an RS-232 driver and receiver, and wire connections to spare port pins and the D-sub connector.

Setting the Bit Rate

A serial port's bit rate is the number of bits per second the port transmits or receives. In basic data links, the bit rate equals the baud rate, and you can use either term as you prefer.

To set a PIC's bit-rate clock, program code configures

FIGURE 1. A MAX3232 converts between 5V logic and RS-232 voltages.



an on-chip timer with a period as close as possible to the width of one bit at the desired bit rate. For example, at 9600 bits per second (bps), each bit is 104 microseconds wide. The CPU's clock source (FOSC) and values in registers determine the timer's period.

In the TXSTA register, the BRGH bit selects a multiplier to use in configuring the timer. In the BAUDCON register, the BRG16 bit determines whether an eight- or 16-bit value sets the timer's period. The SPBRG register stores the value's low eight bits. For 16-bit values, the SPBRGH register stores the upper eight bits. (Not all PICs support using 16-bit values.)

Often, an exact match to the desired bit rate isn't possible. The chip's crystal or other timing source can also introduce error by varying slightly from its rated frequency. In general, the bit rates on both ends of the line can differ by up to about 3% without causing errors. Because you typically don't know the accuracy of the other end's clock, it makes sense to use settings that give the closest match possible.

A quick way to obtain values for a desired bit rate is to consult the tables in the chip's datasheet. For the device's FOSC value and desired bit rate, select the values that give the smallest error.

For example, for a PICDEM 2 Plus board with FOSC = 4 MHz and desired bit rate of 9600 bps, setting BRGH = 1 and BRG16 = 0 gives a close match with a bit rate of 9615 bps. With BRGH = 0 and BRG16 = 0, the best match is 8929 bps, an error of almost 7%.

PICBASIC's hser_baud statement checks the value of BRGH, assumes BRG16 = 0, and sets SPBRG for the closest match to the requested bit rate. To use a 16-bit timer value, set BRG16 and load the SPBRG and SPBRGH registers directly instead of using hser_baud:

```
` Enable the transmitter and set BRGH = 1.
```

```
define HSER_TXSTA 24h
```

```
` Set BRG16 (BAUDCON.3) = 1.
```

```
baudcon = 8
```

```
` Load SPBRG and SPBRGH for the desired bit rate.
```

```
` (Use 19fh for 2400 bps.)
```

```
define hser_spbrgh = 1
```

```
define hser_spbrg = 9fh
```

If your circuit's FOSC value isn't listed in the tables, the datasheet provides formulas for selecting values.

Extending a Link With RS-422

RS-232 is a rugged interface suitable for cables of up to around 100 ft using off-the-shelf, unshielded cables. The exact limit varies with the cable's capacitance. To help prevent data errors, the interface uses wide voltage swings and limits the slew rate – or rate of change – at the outputs. If you need a cable of up to 4,000 feet, RS-422 is an option. Program code that communicates via an RS-232 port can also communicate via RS-422 with no changes.

RS-422 uses balanced lines, where each signal has a dedicated pair of wires. The voltage on one wire equals the complement of the voltage on the other wire. The receiver detects the voltage difference between the lines. Balanced lines are electrically quiet because most noise is common to both wires and thus cancels out.

For best performance with RS-422, use twisted-pair cable. Each pair is two insulated wires that twist around each other every inch or so for the length of the cable. Connect each signal's two lines to wires in the same pair.

The cable should

have a characteristic impedance of 90 to 150 ohms. Characteristic impedance is a measure of the impedance of an infinite line. The value doesn't change with the cable's length. For RS-422, a good choice is network cable such as Category 5e, which has a characteristic impedance of 100 ohms.

Every RS-422 interface must have a ground line or other connection to carry the current that results from any mismatch between the drivers on a line.

Figure 2 shows an

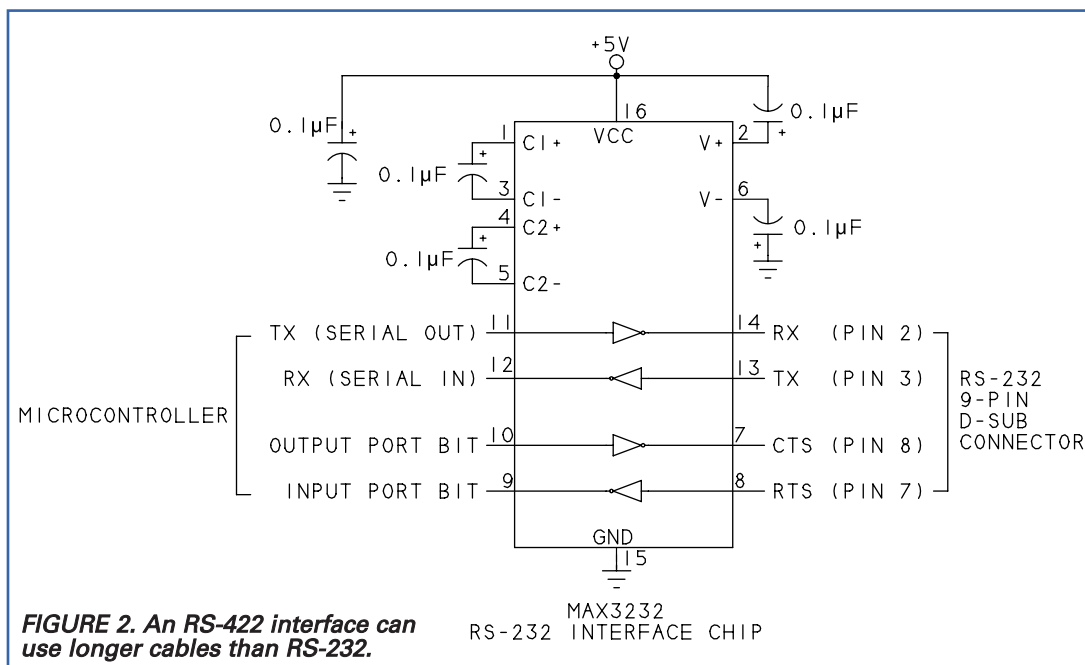


FIGURE 2. An RS-422 interface can use longer cables than RS-232.

RS-422 interface to a microcontroller. The interface chip is a MAX3081. A 100 ohm resistor at each receiver provides a termination that absorbs voltage reflections when the outputs switch. The termination resistor should match the cable's characteristic impedance.

Unlike other RS-422 chips which can handle bit rates as fast as 10 Mbps, the MAX3081 has a limited slew rate that reduces the maximum bit rate to 115,200 bps. An advantage to the chip is that cables of 220 feet or less can eliminate the terminating resistors. The cable can be as long as 4,000 feet at bit rates up to around 90 kbps. At 115,200 bps, the maximum cable length drops to around 3,000 feet.

On a PC, a quick way to obtain an RS-422 port is to attach a USB/RS-422 adapter. An example is USBGear's USB-COMi-M, available from Saelig Company. Other options are RS-422 expansion cards and RS-232/RS-422 converters.

To use hardware flow control with RS-422, add another MAX3081 or similar driver/receiver pair and a twisted pair for each. RS-485 is a similar interface that also supports

serial networks that share a single data path. The MAX3081 is

compatible with both RS-422 and RS-485. **NV**

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TIME *after* Time ...

by Norm Looper
Chief Engineer,
Analog Scientific, Inc.

*A Nuts & Volts Designer's Guide to
reliable oscillators and timers.*

**“Deity resides in
the details.”**

– Ludwig Mies van der Rohe,
Architect

PART 3 — Crystals That Make The World Go ‘Round

Strike a crystal goblet with a spoon, and you immediately have both the attention of your guests and the sympathetic resonance of other goblets on your sumptuous holiday table.

What is happening here? Well, you have created a crystal oscillator that generates acoustic waves in the air. It's an impulse oscillator, wherein the peak movements of the glass and of the ensuing waves of air pressure decay exponentially over time. Your perceived “crispness” of this lovely chiming sound correlates with the actual mechanical “Q” of the singing glass: how sharply the resonant frequency peaks.

Now, common glass is an amorphous solid but arrange the silicon dioxide atoms in a particular rigid rectangular array and you produce a crystal capable of acoustic oscillation in an electronic circuit. And don't stop there, obtain a diamond saw — by slicing the hexagonal crystal at an appropriate angle to its long axis, you can extract a thin slab whose natural acoustic resonance is significantly independent of temperature changes.

Then, grind your slab to a suitable radius and thickness, and you can accurately pre-determine its natural mechanical resonance. Deposit a thin foil of gold on either side of the resultant quartz disc (Figure 1), and bring each foil out on conductive leads.

Voilà! You are now in possession of an oscillator technology of formidable power for use in the everyday world of audio, radio, precision filters, television, radar,

microwave communications, missiles, space probes, computers, power tools, calculators, cell phones, children's toys, alarm systems, and digital watches. It is not surprising that this same everyday world demands several billion quartz crystals every year!

Quartz is a natural mineral, consisting of silicon dioxide in crystalline form. Today, quartz crystals are grown artificially — a vital process in a world of finite resources. Quartz is a piezoelectric material. This means that although it does not conduct electricity, voltages across it can produce internal mechanical strains in the crystal lattice, and these strains can reverse the effect, producing voltages. By applying an AC excitation voltage across the crystal at its natural acoustic resonance, the strains can be optimized and used in feedback to control the frequency of the exciting voltage itself, forcing a sustained, accurate, and stable frequency.

We are used to thinking of the crystal oscillator as solely an electronic device but, in reality, it contains an acoustic control element, vibrating at frequencies usually well above that of human hearing. Piezoelectric oscillators are not just limited to quartz elements, since many ceramics work well also, and these are referred to as ceramic resonators. Physical packages range from those the size of a cigarette lighter down to TO-5 cans, .3” DIP packages, and recently, to surface-mount sizes and pin-outs.

Quartz crystals span an impressive frequency range

from 10 kHz to 10 MHz. By designing the associated feedback circuit with a driving resonance close to one of the crystal's upper odd harmonics, so-called "over mode" crystals can also be constructed to achieve frequencies up to 100 MHz, and above. In such a high volume industry, you would rightly expect a broad selection to be available, and so it is. To enumerate only a few of the common units: units for timing at 32.768 kHz (note that $32768/2^{15} = 1$ Hz); for intermediate frequency generation, such as 455 kHz and 10 MHz; 3.579545 MHz crystals for television color burst oscillators, and 14.31818 MHz for video displays; and a wide range of utility frequencies of quartz and ceramic resonators at multiples of 1, 2, 4, 5, 6, 8, 10, and 16 in the kHz, 100 kHz, and MHz ranges.

As we have seen previously in Parts 1 and 2 of this series, RC relaxation oscillators implemented with IC timers can achieve temperature stabilities of .1%/C and unit-to-unit accuracies from 5% to 12%, depending on the RC components used. We did not discuss LC oscillators: They provide intermediate stabilities between RC and crystal designs. Their stability is suitable for much analog television and radio tuning where low cost is a primary requirement.

However, ultimate frequency stability (ignoring atomic clocks!) is reserved for crystal oscillators. An appropriately cut and excited quartz crystal can achieve remarkable frequency stability as its temperature varies and as it ages over time — and it can achieve frequencies much higher than those of RC oscillators. Stabilities of (\pm) 50 ppm/C are easily obtained and unit accuracy within 50 ppm is common. Aging stability of 1 ppm/day is not difficult to achieve. Be wary of specifications that do not separate out these stabilities, but just state some ambiguous "frequency stability" figure. Also avoid crystal oscillator salesmen in green blazers and white suede shoes.

In this final part of the series on timers and oscillators, let's look at the fundamentals of crystal oscillators, phase locked loops (PLLs), and a few of their correlative design methods.

Crystallizing Your Understanding

We recall that RC relaxation oscillators alternately store and then "relax" electrical energy in the form of electrical charge on a capacitor. While a crystal oscillator is not commonly thought of (or referred to) as a relaxation oscillator, in essence its functioning differs only in the way it stores energy.

Take another look at Figure 1. The electrical energy of the applied AC voltage produces a periodic electrical field in the crystal that distorts it alternately in either direction, doing work on it in the form of stored elastic energy in the crystal lattice. Since

reactive elements are, by definition, those that store and then return circuit energy, we should not be surprised to see that the equivalent circuit for a quartz crystal contains both an inductive element, as well as two capacitive ones.

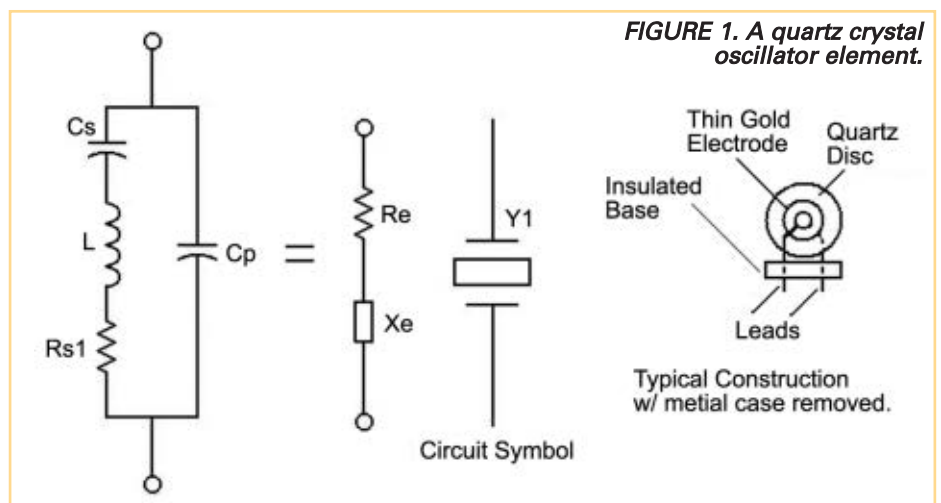
Interestingly, this inductive response is achieved without the direct effect of a strong magnetic field — it occurs by virtue of the phase at which energy is stored and returned relative to the exciting voltage. As shown in the equivalent circuit, we can visualize the crystal as a large inductance of several henries (H), that is accessible to us only through a very small capacitance (C_s), typically less than a picofarad. R_s is only a few kilohms. At its resonant frequency, the crystal provides both positive feedback and loop gain suitable to sustain oscillation.

The "series" resonant frequency of the crystal is the resonance of the LCR branch of the equivalent circuit. The current in this branch reaches a maximum at resonance, and the formula for this is:

$$f_s = \frac{1}{2\pi\sqrt{LC_s}}$$

The parallel capacity, C_p , is the series combination of C_s in the inductive branch and the capacity of the mounting base, and C_p also has a resonant frequency. Quartz crystals are constructed to have their series and parallel resonances close together, within about 1%. This provides the versatility to work the device with a rapid phase shift near these resonances. Voltage-sensitive capacitors called "varactors" can be attached to "pull" the resonant frequency to provide tuning over a narrow range to realize voltage-controlled crystal oscillators (VCXOs).

As shown in Figure 1, the equivalent circuit for the crystal can be reduced to a series resistance R_e , called the "effective resistance," in series with a lumped reactance, X_e . It is in R_e that the crystal dissipates its power as heat, and it is important not to overdrive the crystal since this stresses it and invites both a shift in frequency and outright failure. As we will see, an external resistor can be placed in series with the crystal to limit the drive level. Analogously,



if you strike your crystal goblet too hard, it will shatter.

A Simple Quartz Oscillator

Let's look at a simple quartz oscillator (Figure 2). This is an easy circuit to build and I recommend it as a starting point for understanding what happens. There are three main issues in crystal oscillator design: providing acceptable feedback to the crystal; not overdriving the crystal; and a relentless attention to grounding, shielding, and decoupling.

I have chosen a crystal with a high resonant frequency driven by a single 74HC02D NOR gate to provide loop gain and sustain oscillation. This circuit form is best used above 500 kHz when employing a 74HC series gate as the driving element. If you need frequencies lower than this, I recommend that you choose a higher frequency crystal and then divide it down with a suitable counter, such as the 74HC4020. (An exception to this resides with the 32.768 kHz clock crystal, where good circuit forms are shown by the manufacturers.) This maintains the high minimum slew rate specified for the 74HC logic family, of about 10 volts/microsecond when the input voltage on pin 8 is transiting through the linear region at 2.5 volts. For a sinusoid, the maximum slew rate is easily calculated:

$$\text{Slew rate} = 2\pi f V = 6.28 \times 9.83 \times 10^6 \times (5.0/2) = 1.55 \times 10^8 \text{ volts/second}$$

= 155 volts/microsecond, where V is the amplitude of oscillation and = Vcc/2.

Work your oscillator circuit over a ground plane at digital ground, and keep the supply rail wiring short and decoupled closely at the oscillator.

Using an oscilloscope to obtain a snapshot of the phase relationships does much to understand the circuit

without a detailed mathematical analysis. Use a high bandwidth oscilloscope probe. Adjust the compensation of your scope probe for a flat response, keeping the probe's ground wire short and attached straight to the ground plane. Use a 10:1 probe with at least 10 megohms input impedance. Never probe the crystal driving circuit directly, except for analysis — sample at the buffer output. Trigger your scope on pin 8, the input to the NOR gate, and move around the loop to pin 10 of the NOR, and then to the right end of Y1. Note the accumulating phase lag. A phase lag of 180 degrees occurs twice around the loop, producing the required 360 degrees phase shift for oscillation: once across the NOR inverter and once across the crystal.

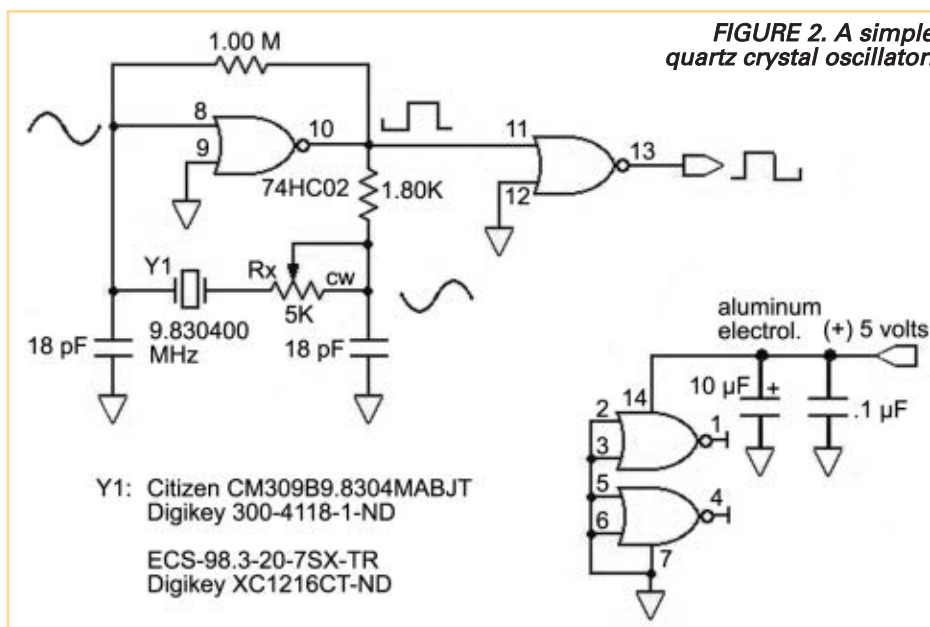
Using a digital frequency meter, adjust Rx to the largest value that will produce a small rise in output frequency when VCC is increased by a volt or so. If the frequency falls, or the circuit shows instability when VCC is increased, you are overdriving the crystal. Since power dissipation and frequency stability of the crystal are important, you will want to test your oscillator above the highest temperature at which it will be used, as well as observe its stability as it ages.

Should You Attempt to Design Your Own Crystal Oscillator?

If you are not designing for volume production — where cost will be primary — I recommend that you simply purchase one of the many integrated crystal modules offered in distributor parts catalogs and pay close attention to the manufacturer's grounding and decoupling instructions. Otherwise, unless you are hewing close to established circuit forms in a conventional frequency range, you should consider one of the many integrated circuit drivers designed just for this purpose. Often, these cost only a few dollars more than the crystal itself.

Crystals have a variety of weaker oscillatory modes

besides their main resonance. These are often referred to as "spurious" modes, which (before the 1970s) was a catch-all term for what they sometimes did, before modern analysis showed that these modes were actually chaotic responses with a logic all their own and not easily controlled by mortals. And one of these modes is to resist oscillation altogether! By contrast, a variety of integrated circuit drivers are offered for your frequency of interest, and these have the strong virtue that they are pretty much guaranteed to drive a particular crystal to oscillate at its primary resonance. Take a look at Figure 3. Here we are using the popular MC1206X chip to support a crystal. This part has been discontinued by Motorola, but is



readily available on-line from houses specializing in discontinued stock. I like it because the feedback loop is closed internally by a carefully designed driving amplifier with appropriate input capacity, impedance, and amplitude limiting for working with a quartz crystal. This avoids overdriving the crystal, promotes good frequency stability, and significantly simplifies your design task.

The PLL: Oscillators Enter a New Phase

Time was, for every really stable oscillator frequency required in a design, a circuit designer constructed a separate crystal oscillator, or at best, contrived to switch one of a set of quartz crystals into an accommodating positive feedback circuit. The 1950s and 1960s were the heyday of amateur radio and there was a large market for cut crystals in the authorized amateur frequency bands, as well as in commercial and military ranges. Both myself and one of the technical editors of this magazine “cut their electronic teeth” on ham radio during this era.

With the advent of the phase-locked loop (PLL) in integrated circuit form, frequency synthesis and synchronization took a great leap forward. Designers were able to free themselves from the tyranny of multiple crystals in order to realize a range of frequencies in a single instrument or communications device. Additional applications for PLLs include AM/FM detection, accurate motor control, and noise generation.

As we see in Figure 4, a PLL uses feedback to hold the output of an otherwise wandering voltage-controlled oscillator (VCO) in phase with a reference oscillator. Since the PLL can lock the phase of a wide range of variant sine wave oscillator frequencies in step with a single reference, a broad spectrum of stabilized frequencies can be produced as an output. And this stability rivals that of the reference oscillator itself. Motorola offers an integrated circuit phase-locked loop in the form of the high speed CMOS MC74HC4046A¹. Looking at this part’s datasheet can be intimidating. Designing with PLLs in production circuits is reserved to those with the courage of the thoroughly uninformed. But you can have a lot of fun playing with them!

Stability and response of the PLL feedback loop are major challenges; I recommend Reference 2 as a guide, where more acute minds provide a detailed analysis. Computing the response of a PLL involves some rather advanced mathematics and should be confirmed by measurements. As in amplifier and filter design, the transient response of the PLL (to a sudden change in VCO frequency) will tell you quite a bit about stability, and as previously discussed in this series, there is simply no substitute for comprehensive and careful testing.

Conclusion

Learning to ride a bicycle or to swim ultimately

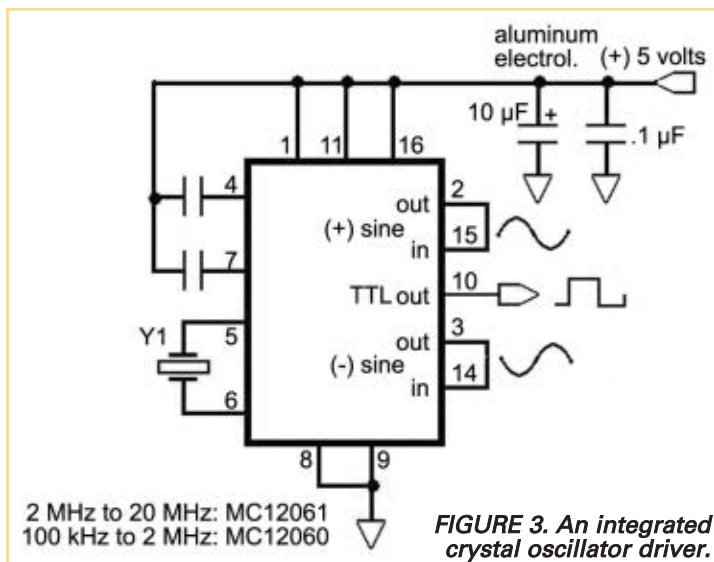


FIGURE 3. An integrated crystal oscillator driver.

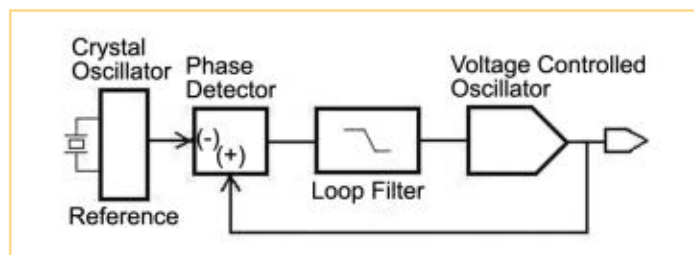


FIGURE 4. A block diagram of a Phase-Locked Loop (PLL).

involves jumping on, or in. Since crystal oscillator design is a non-fatal exercise, you should throw yourself in the pool and have fun. Unless you are an analog gunslinger, stay close to actual circuit designs given in the particular crystal manufacturer’s datasheets when you attempt “cut and fit” departures for your own designs.

Alternatively, if you want to design crystal oscillators for production rather than as a hobby, you should embrace established circuit forms, master the appropriate mathematics, and test your designs all the way to failure. A comprehensive discussion of crystal and ceramic oscillators would require many more pages than contained in this fine periodical. In any case, I hope I’ve pointed out the descriptive essentials, the caveats, and some of the potholes along your oscillator journey. **NV**

A small kit (with a printed circuit board and all parts for the crystal oscillator shown in Figure 2) is available from the author for \$14.95, with \$5 for shipping and handling. Contact the author at chiefengineer1284@analogscientific.net or 619-795-1920.

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- (1) *High-Speed CMOS Data*. Motorola, DL129/D, Rev 6. May 1996.
- (2) *Radio Frequency Electronics*. Jon B. Hagen, Ph.D. Chapter 14, pages 128–140. Cambridge University Press, 1996. ISBN 0-521-55356-3. Dr. Hagen is the Director of the National Astronomy and Ionosphere Center at Cornell University.

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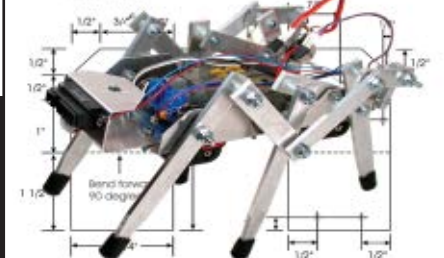
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ROBOTICS

PERSONAL

UNDERSTANDING, DESIGNING & CONSTRUCTING ROBOTS & ROBOTIC SYSTEMS

■ BY VERN GRANER

A DROID OF YOUR OWN

IS IT POSSIBLE TO BUY A “KIT” OF R2-D2 parts and make your own full-sized replica R2-D2 droid? Nope. Is it possible to find a group of talented builders and crafters who are passionate about building droids and who will go to great lengths to help you create your own? You betcha!

The year was 1977 ... the theater in downtown McAllen, TX was playing *The Exorcist II* on screen 1 and on screen 2, was a little film called *Star Wars*. Since I was 14 at the time and I couldn't see *The Exorcist* (the ushers were sticklers about IDs), so I opted for *Star Wars*. Though I liked the horror genre, I'd always been a big science fiction fan, so there really wasn't much of a choice there to begin with. Though *Star Wars* was a

movie full of action and adventure, high drama, and low villains, it also introduced me to a little fellow whose model number has become synonymous with small robots — R2-D2.

Though the English-accented C3PO had his own unique charm, his sidekick R2-D2 was just beyond cool! Fitting perfectly into the ranks of other Hollywood robots such as B9 (a.k.a., The Robot) of *Lost In Space* fame, Robby from *The Forbidden Planet*, and even Huey, Dewey, and Louie from *Silent Running*, “artoo” (as Luke called him) was cute, lovable,

and very different from other robots seen previously on the silver screen. Though some have commented that R2 looks more or less like a rolling trash can — or even a futuristic shop vac — his shape and size, combined with his unique vocabulary of sounds has made him unmistakable to a generation of science fiction fans.

EVERYBODY WANTS ONE ... I WANT ONE TOO!

■ Sami Graner posing with Chris James' R2-D2 droid at RoboGames 2007.



With the personal computer boom of the late 1970s and early '80s, a number of manufacturers rushed in with various personal robotic offerings, some of which were clearly inspired by the R2 droid. A good example is the RB5X from General Robotics Corporation (Figure 1). Like many kids at that time, I dreamed of owning a shiny plastic robotic companion, however the majority of robots marketed for home use in the 1980s were just too pricey to be affordable for regular folks. Most cost many thousands of dollars and were more likely to be purchased by

■ FIGURE 1. The RB5X robot from General Robotics Corporation.

a school district or a university computer department than by a parent for some kids' birthday gift.

In the late 1980s, I did finally manage to acquire an R2-inspired robot from IDEAL toys — the Maxx Steel robot (Figure 2). Maxx was roughly the same height as an R2 (actually, a bit shorter) and he had dual arms that he could raise and lower. At the end of the arms he sported a rubber-lined “claw” that could hold a soda can, but not much else. He also spoke using a limited set of plain English canned phrases that you could string together to make sentences. You could program sounds, lights, music, and motion to make little “shows” he could perform on cue. Though cute and fairly advanced for his time, he was really more of a toy and frankly, he just wasn't R2.

A LONG TIME AGO ... IN A BROWSER FAR, FAR AWAY ...

Flash forward a few years (decades?) and I somehow ended up as the president of The Robot Group, Inc., a very active art and technology non-profit group. We have lots of talented members and a history of using our technological creations for community outreach and technological evangelism. Before one of our meetings, I was rummaging around the Internet for some clip art when I stumbled across the R2-D2 Builders Club (see Resources for link). They had an amazingly active membership and had even managed to compile a complete set of plans that would help someone to build their own R2-D2 unit!

I read through their message forum with excitement and drooled over galleries full of pictures of droids in various stages of construction and complete, fully-operational R2-D2 droids, as well! Creating an R2-D2 would be a perfect fit for our group, and would also be perfectly in line with our interest and events (not to mention it would place a real R2 within touching distance!).

I downloaded some of the plans and after having a closer look, my

■ FIGURE 2. The author's Maxx Steele robot.

enthusiasm was dimmed a bit when I realized just how much metalworking and/or wood crafting would be required to create some of the custom parts for an R2 unit. Though I knew that myself and other members of The Robot Group would be able to help out with the wiring, programming, radio control, and other robotic aspects of the droid, it would take a specific kind of experience and skill to create the movie-accurate mechanical “skeleton” of R2. We would need to find an expert for that. Luckily, we knew just where to look.

THOSE WHO CAN'T DO ... FIND SOMEONE WHO CAN!

Some of you may recall from my previous columns, the mention of a good friend and colleague of mine named Rick Abbott. Rick is a talented “old school” machinist and long-time member of The Robot Group. He always seems to be able to come through with just the right parts to make “Slot A” connect to “Tab B.” I've always been a bit in awe of his skill, so I figured the project was probably well within his ability to do. What I didn't know was if building a replica R2-D2 droid would be something that would interest him. When I first broached the idea, he seemed eager to pit his skill against the challenge. I handed over all the web links and the printouts I had created from the plans and hoped for the best.

After a few weeks, he brought a small box to our weekly Robot Group meeting. He opened the box and displayed a small, finely worked piece of aluminum (Figure 3). He said “this is a shoulder hub

■ FIGURE 3. Rick Abbott showing his hand-machined aluminum R2-D2 shoulder hub.



for an R2-D2 robot.” At that point, I knew he was hooked!

FORM FOLLOWS ... SCRIPT?

Typically, the form of a given personal or industrial robot will closely follow the parts used to create it or the function(s) it is designed to perform. Small experimental robots like the Boe-Bot from Parallax or the Hexcrawler from Crustcrawler have no discernible cosmetic features. Their





■ FIGURE 4. Rick Abbott's R2-D2 ankle cylinder.

chassis are built with functionality in mind — providing mounting points for add-on devices and making all aspects of the robot visible for demonstration, education, and experimentation. Even larger robots such as those built for robot combat will rarely have purely cosmetic components.

Though most combat robots have a “body,” it is usually there as an active part of the robot (i.e., armor). The battery cases contain,



■ Leg assembly with ankle attached.

parts. When Rick started to build the R2 unit, one of the first things he built was a very detailed and completely non-operational part called an ankle cylinder (Figure 4). He would hold it up and talk to me about the angles of the surfaces and the jigs he had to build to get it right and then he

would plaintively say “well, it’s pretty but it doesn’t do anything!”

This was new territory for Rick (and the rest of us, as well) since, in most cases, each thing we fabricate usually has a specific purpose. For example, when Rick built his Stirling engine (Figure 5), each part had a reason to be made, a place to be, and a purpose to perform. If he made the part incorrectly, the device would perform poorly or would simply fail. In the case of R2, many of the most intricate and difficult to create parts are purely cosmetic. This is not to say that the creation of the part is any less exacting; only that when you’re done, the ultimate test isn’t whether or not the final assembly works, but rather if it looks right.

R2-D2 TRIVIA AND LITTLE KNOWN FACTS

- The sounds R2-D2 makes are based on the inarticulate emotive sounds such as those made by babies before they attain the power of speech. This was done to increase the chances of the audience identifying with and responding to the character. The composite sounds make R2 more “human” in nature, in spite of the non-humanoid body.

- George Lucas came up with the name R2-D2 from the heading on a cue sheet for the making of the film *THX-1138*. “R2-D2” was shorthand for “Reel 2, Dialog 2.”

- In the first *Star Wars* movie, when R2 was in a two-leg stance, it was actually the actor Kenny Baker in an R2-D2 “suit” that was responsible for all the motions of the droid. When the droid was rolling, it was actually a radio controlled unit.

- When George Lucas proposed building the droids for the first movie in 1976, the animatronics experts he consulted said it would be “virtually impossible” to create mechanical beings with the functionality he described without investing thousands of dollars and multiple years. Turns out they were right.

- In the first *Star Wars* film, the prop department created R2-D2 droids in “two-foot” (i.e., standing) and “three-foot” (i.e., driving) stances for filming. They only created one prop that could transition from two-foot to three-foot stance using a simple pneumatic cylinder. However, this droid had to be manually reset into the two-foot position. Only droids built by the R2-D2 Builders Club have been able to accomplish a complete two-foot to three-foot and back again transition (called a “2-3-2”).

THE SITH IS IN THE DETAILS

Though there are plans, diagrams, and example finished droids to use as a reference, each droid is a unique creation of its builder. Almost all finished droids

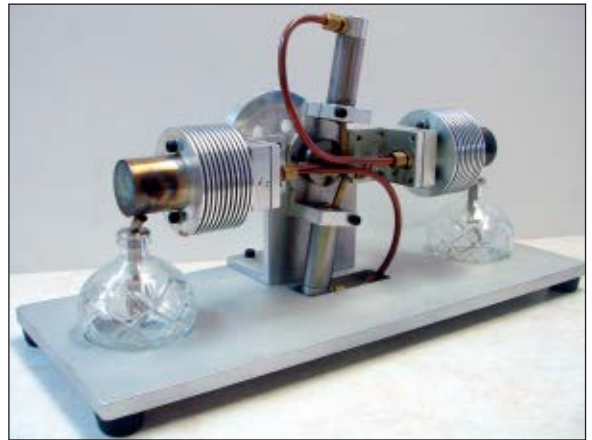
■ R2-D2 ankle assembly.



look identical on the outside, however, on the inside things can be done VERY differently on each droid. The system used to rotate the dome, the system used to drive the wheels, the various accessories such as the periscope, holoprojector eye motion, and the like may or may not be in every droid. Also, the internal wiring, motor speed controllers, sound system, radio control, and sound playback systems vary from droid to droid (Figure 6). History has also shown that a broad range of material may be used to create these droids. A basic static unit (i.e., non-motorized) can be made from relatively simple

■ FIGURE 5. Model Stirling engine by Rick Abbott.

materials such as a section of cardboard tube concrete form, wood for legs, and a painted acrylic "squirrel shield" for a dome. The more advanced builders sometimes go for a complete aluminum droid made from all machined metal parts. I have seen resin and wood R2 units that are beautiful to behold (Figure 7), but for me a full-aluminum R2-D2 is the most exciting as it has the look and



feel of a "real" droid. I'm really looking forward to Rick finishing his.

EXCERPTS FROM FREQUENTLY ASKED QUESTIONS ABOUT THE R2-D2 ROBOT BUILDERS CLUB

How the Club works

The Club is as much a social club as it is a technical forum; feel free to discuss any experiences you have had building your droid.

If you wish to ask something or discuss something that is not directly related to building an R2, just place an OT: (OffTopic) designation in the title of your post. For example, if you wish to discuss the color of C3P0 and you think someone in the group may be able to help, you may title it something like

OT: C3P0 colors?

Please note, that while the club is willing to discuss some topics not directly related to R2, you should not drift too far from the subject. Also, we do not under any circumstances discuss anything which may be considered "profiteering." We do not sell parts for profit or sell complete R2s, as this would breach copyright rules. We also do not discuss VCDs or DVDs, which have been pirated or downloaded off the net. We do not allow SPAM or sales pitches or advertising for any other products.

Also note the group individuals do not make a habit of answering questions via private email, as usually if the question is worth asking, it is

worth posting to the group. However, should a member decide that the information is not worth posting to the group they may then elect to continue a private conversation with the person with the question.

Remember, we do NOT sell complete kits.

Legalities: Copyright Generalization

To create replicas of ANYBODY'S intellectual property (including but not limited to Lucasfilms) is NOT a violation of any copyright law on the books today. To display PICTURES of a REPLICA of somebody's intellectual property and label it as such with no deception intended is NOT a violation of any copyright law on the books today. To create a replica of somebody's intellectual property and then try to SELL it for a profit (even as little as one cent) IS a violation of copyright law. To create a replica of somebody's intellectual property and then try to REPRESENT it as the ORIGINAL (even if it's not for profit) IS a violation of copyright law.

What will it cost me?

This question has SO many variables. The main one is you and what kind of handyman you are. You can spend anything from \$100 to \$3,000 depending on materials, finishes, and electronics.

If you make the parts yourself, the cost can be in the low/mid hundreds, taking a year or two. If you buy most parts, the cost can be in the thousands and take about a year. If you add motors and R/C, add on several months and a couple

hundred. You have to factor in how handy you are, how much time you want to put into this, and what you want your R2 to do.

It also depends if you have a good set of tools to work with; the actual costs of materials can be quite inexpensive, however if you are required to buy tools you do not have to build it, then that becomes an added cost.

It will also depend on what material you want your parts made of: plastic, aluminum, or wood.

The finished result will be up to you; even a very cheaply built R2 can be very accurate.

A good recommendation is to leave the electronics/motors and R/C equipment purchases till last. This way, if your budget changes or your building designs change you will not be spending money on equipment that you may not need at the end. These are also the more expensive parts of any droid.

Where do I get a kit?

You will not find an "R2-D2 in a Box" type kit from this club. This group is based on communicating with each other on how we built our own droids. You will find a number of members offer individual parts but not an entire kit.

Try posting what you're looking for, one or two individual parts at a time. The people that supply those parts will be able to contact you.

The above excerpt is courtesy of the R2BC and the robotbuilders.net website. The complete FAQ is available at www.robotbuilders.net/r2.



■ Rick Abbot with R2-D2 frame.

THIS IS THE DROID YOU ARE WORKING FOR

Though Rick has made amazing

■ FIGURE 7. Dave Calkins' wood and resin R2-D2.



■ FIGURE 6. Chris James' R2-D2 internal wiring and control electronics.

it was quite a sight. The people streamed along behind his droid like it was the Pied Piper and — in a way — it really was! Chris can use his remote control to trigger the droid to play the “Cantina Band” song from its little speaker. The kids all start to dance around while the parents tap their feet in time and Chris wiggles the joystick to make R2 dance. It’s really an amazing sight. No matter where he and his droid go, they’re sure to put a smile on every face.

R2 B.C.

No, we’re not talking about a prehistoric droid. We’re talking about the R2-D2 Builders Club. Founded by Dave Everett in Australia in 1999, this is the place to go if you are interested in building a droid of your own. To learn more about R2-D2 builders and the amazing and touching story of how

progress towards a complete R2-D2, he’s not far enough along yet to actually drive it around and show it off (Figure 8). However, I was lucky enough to meet up with someone who had a completed droid at RoboGames in 2007. Chris James rolled his R2 unit up to the *Nuts & Volts* table and

■ FIGURE 8. Rick’s R2-D2 at Maker Faire Austin in 2007.



RESOURCES

■ The Official R2 Builders Group website (need a password to enter)
www.astromech.net

■ R2-D2 plans, photos, and message board
<http://movies.groups.yahoo.com/group/r2builders/>

■ The Robot Group
www.TheRobotGroup.org

■ R2-D2 Trivia Source
www.starwars.com/episode-i/bts/profile/f19990414

■ Hexcrawler robot from Crustcrawler
www.crustcrawler.com

■ Boe-Bot from Parallax
www.parallax.com

■ Chris James
www.artoo-detoo.net

a pink droid named "R2-KT" came to be, please pick up this month's issue of *SERVO Magazine* and check out the feature article "The R2 Builders Club and the Jedi Code." In the meantime, Rick will be continuing to build parts for his R2 unit and as he progresses, I'll make sure to take lots of pictures and share his progress in the future. **NV**

Special thanks to Rick Abbott, Chris James, and the good folks at the R2-D2 Builders Club!

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■ BY L. PAUL VERHAGE

2007 SPACEWARD GAMES: Part 2

THE SPACEWARD FOUNDATION IS AN EDUCATIONAL 501(c) (3) non-profit dedicated to the creation of the space elevator (see the March '08 issue of *Nuts & Volts*). But the Spaceward Games isn't just about space elevators; it's about developing the technology that will kick-start our migration into the solar system. This month, I want to conclude my report on the most recent Spaceward Games by describing the solar racing and ultra-strong materials competition — the other half of their challenge that I watched last year.

Unlike its other challenges, Spaceward's Light Racers Challenge isn't part of their NASA Centennial Challenge contract. Instead, non-NASA donors sponsor this fun event. Entries (usually small

R/C cars) have to drive down a 60 foot long track solely under beamed energy. There's no time requirement for the race, just the distance requirement. The energy source for the racers comes from the beam of a

high intensity spotlight that tracks the light racer as it travels down the course. The light racer competition is a challenge designed for young and old alike with three entry levels: school, family, and grown-up. The school and family levels are team entries and a child (under the age of 16) must operate the team's racer. The challenge charges a \$25 entry fee and has a total prize purse of \$10,000. The winning light racer can earn \$1,000 to \$2,500 while the runner-up can earn \$500 to \$1,000.

My fiancée Rachel and I watched eight teams compete in the Great Solar Racer Challenge in Climber Row — the building where the climber teams housed with their entries. The teams (in alphabetical order) we watched and visited were:

- Eddington
- Family LeBaron
- Farmington Junior High
- Kansas City Space Pirates
- McGill
- Michael Flora
- Technology Tycoons
- TSA-Mesa

Some of the racers took off with great enthusiasm only to fail part way down the track. It appeared to me that the racers were suffering from

SHACKLETON

The Light Racer Competition replicates conditions expected at the lunar north and south poles. One place in particular is the crater Shackleton, which is located close to dead center on the lunar South Pole. Observations from the NASA spacecraft Lunar Prospector indicate this 12 mile crater is over 1-1/2 miles deep. Inside its perpetually dark center — and in similar neighboring craters — Lunar Prospector detected the signal of hydrogen-rich regolith (lunar soil).

Why should the regolith inside Shackleton and its neighbors be hydrogen rich while the rest of the lunar regolith is not? Comet and water-rich meteoroid (primarily chondrites) impacts send plumes of water vapor across the lunar surface. Over time, the moon's high day time temperature and low surface gravity drive the water molecules off the moon. But as they skip across the hot lunar surface, water molecules may find themselves inside a cold lunar crater, shielded from direct sunlight, before they have a chance to escape. If the crater is in perpetual darkness at the lunar poles, then the water

molecules will freeze there for billions of years. If astronomers understand the situation correctly, millions of tons of water ice could be waiting in these craters for the first human lunar outposts. This lunar resource will yield drinking water, coolant, and rocket fuel for early lunar explorers that they don't have to bring with them from Earth. The cost savings of living off the land by using in-situ lunar water will be astronomical (pun intended). All we need to do is land a rover inside Shackleton to collect, melt, and filter the water.

There's another benefit that craters like Shackleton provide. The rim of Shackleton is tall enough that portions of it see daylight for 90% of the lunar day (27 out of 29 days). Referred to as Peaks of Eternal Sunlight, they're the perfect location for solar power stations. Any beaming technology that can transfer power from the solar arrays on the Peaks of Eternal Sunlight to a rover deep inside Shackleton will save the weight and cost of tens of miles of copper wire. And Spaceward intends to help make it happen.

the $1/r^2$ nature of light. When the racers doubled their distance from the light source, the light's intensity on their solar array dropped off by a factor of four. A second factor that appeared to be an issue was the light racer's inability to rotate their solar cell. Therefore, as they drove down the track, the orientation between their solar array and the light beam became less perpendicular. The combination of reduced light intensity and less than optimal orientation resulted in lower power being generated for the racer's drive motor.

Even with these problems, there was a winner this year. The families of the Kansas City Space Pirates spent about an hour building their racer (since it was cloudy, they couldn't run their climber) and for their entry fee and hour of work, they won \$2,500. Figures 1-7 show my scrapbook of the 2007 light racers.

IDEAS FOR MY 2008 LIGHT RACER ENTRY

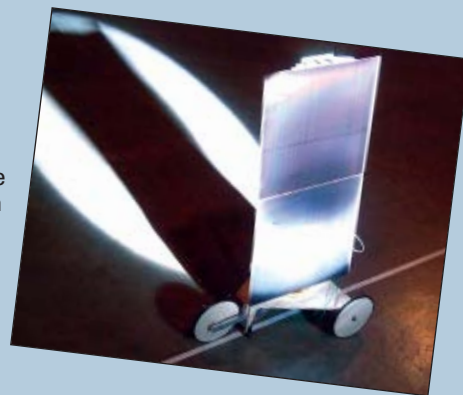
While I don't know which motor or solar cells I'll use (yet), I do have an idea for my light racer's chassis. I often make booms for my near spacecraft out of Styrofoam sheet laminated in thin plywood. And in my experience, the resulting booms are very stiff, strong, and lightweight. Therefore, I plan to make my light racer's chassis from 1/2-inch thick Styrofoam cut to the proper shape and then epoxy 1/32-inch plywood over it. It's easy to attach a solar array and motors to the chassis using epoxy and basswood blocks. By the way, I'll use Cell Foam 88 for the chassis — a new Styrofoam sheet material available at most hobby stores.

I'd like to use plastic peanut butter jar lids for the wheels and I'll drill large holes into them (especially near the rims) to reduce their angular momentum. With holes, the wheels will spin up to speed faster. Then I'll add traction to the wheels by wrapping their rims with rubber bands. Because the lids are made of thin plastic, it will be easy to add something like a servo horn to them



■ FIGURE 1. A four-sided array of Power Film (www.powerfilmsolar.com) sits on top of this racer. There's no pointing problem here, but unfortunately, this array is only on the order of 9% efficient.

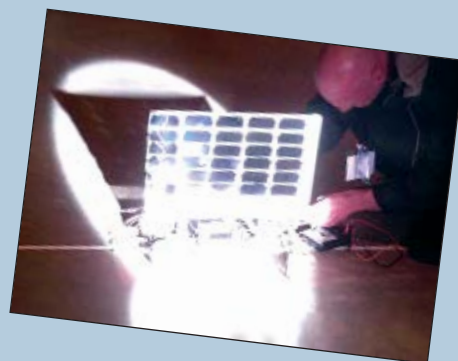
■ FIGURE 2. This array rotated to face the light beam as the racer drove down the track. A set of photocells were the array's light orientation sensors.



■ FIGURE 3. This racer was radio controlled. If I remember correctly, the R/C kept the array pointed at the best angle as the racer drove down the track.



■ FIGURE 4. I don't remember how the race went for this entry.



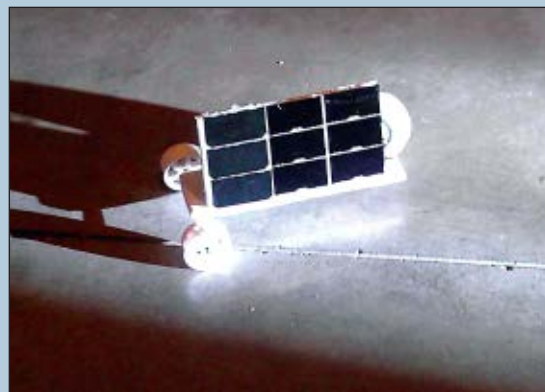
■ FIGURE 5. This is another racer that I don't recall how the drive went.



■ FIGURE 6. This year's winner by the Kansas City Space Pirates.



■ FIGURE 7. The children of the Kansas City Space Pirates and their winning entry.



THE PASCAL

The Pascal is a unit of pressure or stress. Pressure and stress are composite units of force per unit area. The pressure and stress unit most readers will be familiar with is the PSI, or pound per square inch. The Pascal is defined as the metric composite unit of newtons per square meter and this makes one PSI equivalent to 6.89 kilopascals (kPa).

for their mounting to the motors.

Now I just need to find a good source of high efficiency solar cells (probably surplus), a motor, and perhaps a microcontroller. The best place I think to find motor efficiency information is at my local hobby store. I'm sure R/C race car enthusiasts can point me to the best motors (they'll probably be the expensive ones with neodymium magnets). Then there's the issue of gear trains. I need to know if they're included inside some motors or if I can add one to the racer chassis. The solar cells will be purchased surplus

and glued (with silicon rubber) to a Styrofoam sail. Since the racer is so simple, its microcontroller (if indeed I need one) will be a PICAXE-08. I'll use relays rather than an H-bridge to run the motors since relays don't drop voltage (which is a waste of power in a power limited racer). Sounds like I have my work cut out.

THE SPACEWARD MATERIALS CHALLENGE

To enable the affordable expansion of our space program, we need — among other things — super strong materials. Materials that are lightweight for their strength reduce the amount of fuel that a spacecraft requires to perform its mission while increasing its safety margins. And it's not just the spacecraft and its equipment that benefits, the space elevator will become a reality once sufficiently strong materials in sufficiently large amounts exist. To help bring about this revolution in super strong materials, Spaceward has

developed a materials challenge from their NASA Centennial contest called the tether pull. According to Dr. Bradley Edwards of the Spaceward Foundation, the strength required to build a space elevator is on the order of 100 gigapascals (GPa). Currently, the only material known to be this strong is carbon nanotubes (CNTs) with a theoretical strength of around 300 GPa. However, current CNTs are too short and don't meet their theoretical strength. Until recently, centimeter lengths of 9 GPa strong CNTs were the best that could be produced. That's nowhere near the 60,000 miles of 130 GPa strong CNTs needed to make a space elevator.

To win this year's Materials Challenge, entries had to produce a tether 50% stronger than the house tether. This year's house tether was a two meter long, three gram heavy cable of Zylon fiber. Zylon has a breaking strength of 5.8 GPa, therefore to win, a competing tether had to be two meters long, no heavier than two grams, while having a breaking strength of at least 8.7 GPa. Since no tether entry last year could beat the house tether by 50%, the prize purse for the 2007 Materials Challenge was worth \$500,000.

There were two teams competing for this year's tether pull. The first was last year's defending champions, Team Astroaraneae led by Michael Remington of Aerojet Corporation. This year's newcomer was Team Delta-X from MIT lead by Stephen Steiner. Before either could challenge the house tether, the two tethers had to challenge each other first (Figure 8).

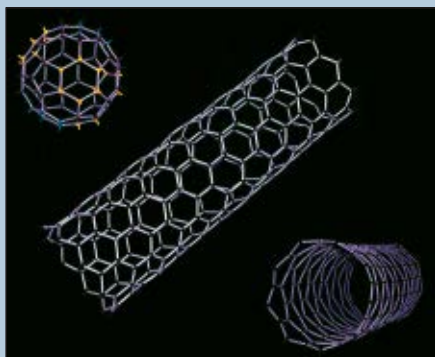
Team Astroaraneae's entry was a proprietary tether, so I can't tell you what it was made from. However, Team Delta-X announced that their tether was CNT, a real two meter long carbon nanotube tether weighing two grams and looking like a slick black plastic cord! (The MIT team is sponsored by the company Nanocomp Technologies of Concord, NH.) The amount of CNT in the Team Delta-X tether would normally retail for \$50,000. However, Nanocomp donated the CNT material for free as part of their

THE FORMS (OR ALLOTROPES) OF CARBON

Back when I was taking chemistry, we learned there were two forms, or allotropes, of carbon: graphite and diamond. These two represent extremes. Diamond is the world's hardest known substance and graphite was one of the softest. Despite their differences, both consist of just carbon atoms. In diamond, the carbon atoms form a three dimensional structure and in graphite, carbon atoms are arranged in the form of a sheet. The three-dimensional structure of diamond makes it incredibly hard while the flat sheet structure of graphite lets it easily separate into plains.

In 1985, a new allotrope of

carbon was discovered — the Buckminster fullerenes (Bucky Balls, for short). Bucky balls are spherical in shape and look like two geodesic domes tied together. A second form of the fullerenes was discovered in 1992 — the carbon nanotube (CNT) — and they look like chicken wire rolled into a tube. CNTs are tiny at only a few nanometers across and recently up to a centimeter or more in length. That's 0.0000002 inches across and 1/2 inch long. That gives them a length-to-width ratio of over two million to one!



■ At the atomic level, the Bucky Ball on the left looks like a miniature soccer ball with its hexagonal and pentagonal arrangements of atoms. The nanotubes in the center and on the right only have hexagonal arrangements of atoms. Because of this, they only curl in one dimension or into a tube. Image from the Swiss Nanoscience Institute, www.nccr-nano.org.



■ **FIGURE 8.** The torture chamber of tethers. A pair of two meter long tether loops are tested against each other in this jig. Ouch!

collaboration with the MIT team. Stephen Steiner from MIT told me that the carbon in their CNT tether is not that expensive. It's the cost of running a cutting edge company like Nanocomp Technologies that makes it expensive. I foresee the day though when the use of CNT is ubiquitous in our society that CNT tethers like Team Delta-X's will be as affordable as twine (Figure 9).

At the tether pull, two tethers are loaded into the jig and pulled simultaneously. The tether that fails first is eliminated and the winner then



■ **FIGURE 9.** Dr. Edwards holding the first CNT tether. Until this day, the public only saw CNTs from under a microscope. It looks like a glossy black plastic twine.

goes on to face the house tether. The MIT tether wasn't a woven loop of CNT; there was too little time for them to do that. So instead, MIT made the CNT tether into a loop by tying its ends together with a knot.

However, CNT is too slick to hold knots. So very early in the test, the knot in the CNT tether pulled apart. The test ended at a force of only 200 pounds. Team Astroaraneae decided not to test the house tether

since it required that their tether stand up to a punishing 1,800 pounds of force on the jig. Team Astroaraneae has tested their tether to 1,336 pounds of force, which is pretty darn good for a two gram cord.

Onwards and Upwards,
Your Near Space Guide **NV**

WANT TO KNOW MORE?

Here are the websites where you can read more about the light racers and super strong tethers:

Team Astroaraneae
www.astroaraneae.com

Team Delta-X
www.teamdeltax.com

Nanocomp Technologies
www.nanocomptech.com

The Light Racer Competition
www.spaceward.org/lightRacers

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■ BY FRED EADY

BUILDING A CPLD DEVELOPMENT KIT

POUR SOME DISTILLED WATER on that dried up soldering tip cleaning sponge and fire up your soldering station. In this edition of Design Cycle, we are going to tie down that Xilinx XC2C64A CPLD you see in Photo 1 onto the ExpressPCB printed circuit board we're beginning to put together in Screenshot 1.

By the time you read through this month's Design Cycle text, we will have fabricated an ExpressPCB CPLD development board and populated it with a XC2C64A CoolRunner-II and some additional CPLD test and development hardware. Along the way, we will also put together some C-like ABEL programming statements that will demonstrate just how easy it is to convert a combination of XC2C64A logical inputs into our desired set of XC2C64A logical outcomes. The whole trip would be useless if we didn't logically blink some LEDs with the XC2C64A. So, count on that happening, as well.

DESIGNING AN XC2C64A DEVELOPMENT BOARD

In the previous installment of Design Cycle, we attended CPLD 101 and examined the innards of a typical CoolRunner-II CPLD. Before we can sign up for CPLD 201, we'll need to have some physical CoolRunner-II hardware to manipulate. I've chosen to design our CPLD development board around the Xilinx XC2C64A, which happens to be a 64 macrocell Xilinx CoolRunner-II chip.

Recall from our earlier discussions that CoolRunner-IIs are built around macrocells that are integral parts of FBs (Function Blocks). The FBs are then interconnected by the AIM (Advanced Interconnect Matrix). The AIM feeds each FB with 40 true and complemented inputs. In the case of the XC2C64A, we

have four FBs at our disposal with each XC2C64A FB folding 16 macrocells into its logical structure.

The XC2C64A is a 1.8-volt part that accommodates various I/O logic levels. Although the XC2C64A I/O subsystem can handle voltages from 1.5V to 3.3V, the XC2C64A I/O subsystem is not 5V tolerant. However, 3.3V systems are becoming more common even among us hobby types. So, our development board hardware design will fit the XC2C64A I/O pins to 3.3 volt LVTTTL and LVC MOS33 logic levels. The letters "CMOS" in LVC MOS33 infer that the LVC MOS33 logic level transitions can traverse from rail-to-rail. I'm sure that all of you know what "TTL" is. LVTTTL is to 3.3 volt logic what TTL is to 5.0 volt logic. LVTTTL is the standard for general-purpose 3.3 volt systems. We can specify the XC2C64A I/O logic voltage drive scheme when we write our XC2C64A application code.

Take another look at the far left of Screenshot 1. What you see is a pair of large heatsink pads supporting a pair of SOT-223 packaged 800 mA LM1117 linear voltage regulators. The XC2C64A core voltage (1.8 volts applied to the Vcc pin) is provided by VR2 (an LM1117-1.8) and its associated filter capacitors (C5-C8). The voltage applied to the XC2C64A pins VccIO1 and VccIO2 determines the logic drive

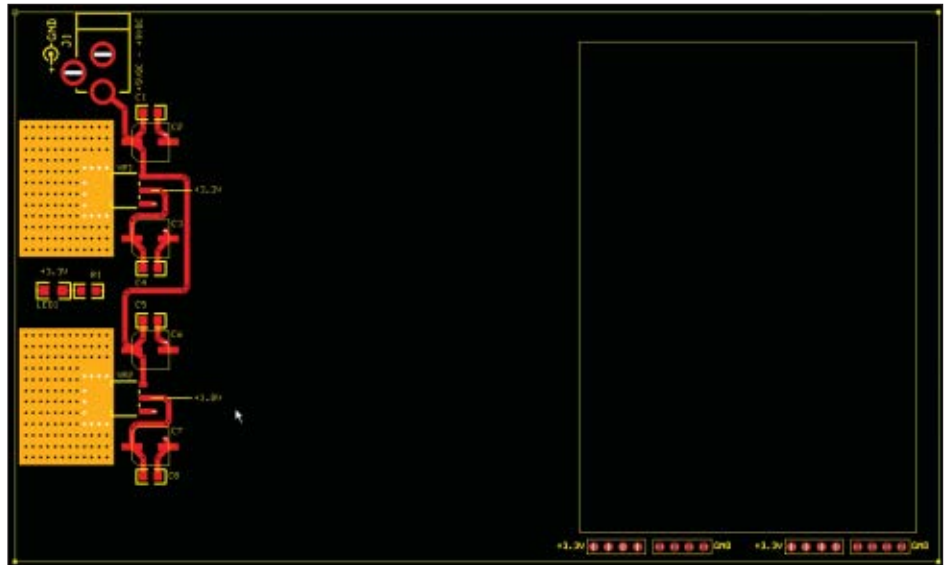


■ **PHOTO 1.** If synthesizing logic with silicon and solder interests you, this is 44 pins of heaven. We could have also used a 44 pin VQ44-packaged XC2C32A in our development board design as the lower macrocell count XC2C32A has the identical pinout of its big brother — the XC2C64A.

■ **SCREENSHOT 1.** I've laid in the XC2C64A power supply circuitry and I've sized the CPLD development board PCB to accommodate a small Jameco solderless breadboard.

type of the XC2C64A I/O subsystem. In our case, the XC2C64A I/O subsystem is powered by 3.3 volts, which is provided by the output of linear regulator VR1, an LM1117-3.3. Thus, depending on the application, we can drive the XC2C64A output pins using LVTTTL or LVCMOS33 logic levels.

I sized the XC2C64A development board's FR-4 epoxy panel to include a Jameco JE21 solderless breadboard. You can fill in this area with your choice of pads if you don't wish to use a solderless breadboard in your personal design. Another option is to eliminate the breadboard area all together if you don't feel you'll need it. In either case, you'll have download access to my version of the four-layer ExpressPCB XC2C64 Development Board printed circuit board (PCB) file to use as-is or modify to suit your needs. In Screenshot 2, I've laid in additional pads for the XC2C64A and its JTAG interface circuitry. I plan to populate the XC2C64A I/O terminations with a 0.1" center inline female header. The female header will allow me to use standard solderless breadboard wire to interface the XC2C64A to any electronics that I may wish to pile onto the solderless breadboard. What you don't see in Screenshot 2 is the XC2C64A's 1.8 volt power plane. We must supply the XC2C64A's Vcc pin with 1.8 volts while the VccAUX, VccIO1, and VccIO2 pins need to see 3.3 volts. The VccAUX pin is the entry point for the JTAG supply voltage. I won't show you the 1.8 volt and 3.3 volt power planes here. However, you can download the layout file and look at them first hand. What you will see is that I simply carved out a 1.8 volt copper region that connects the output of the LM1117-1.8 to the



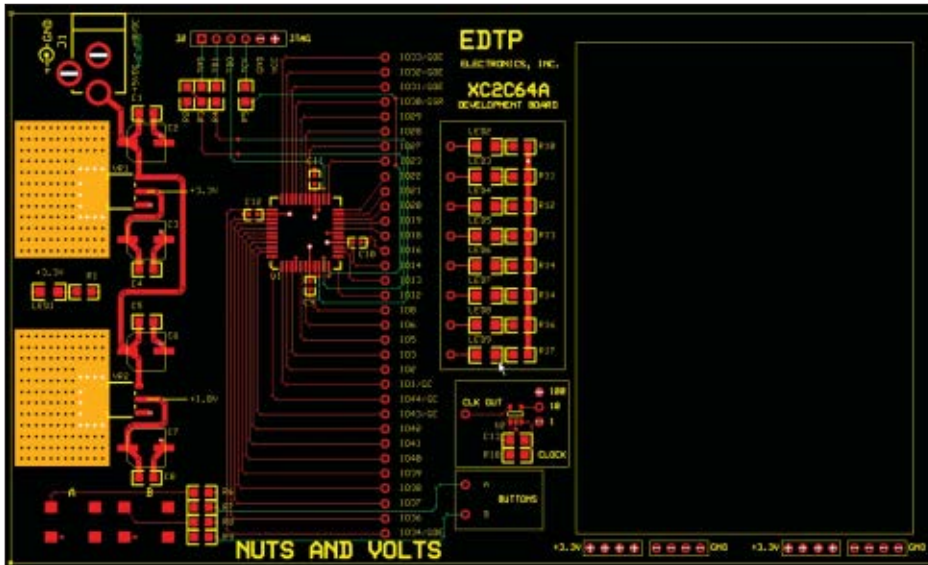
XC2C64A Vcc pin. The remainder of the power plane is fed by the output of the LM1117-3.3.

If you're wondering why the XC2C64A has a pair of VccIOx pins, here's why. The XC2C64A divides its I/O subsystem into a pair of I/O banks that can drive differing logic levels. For instance, we can use one bank to drive 2.5 volt logic by supplying 2.5 volts to VccIO1. The other bank can be driven with LVTTTL levels by applying 3.3 volts to VccIO2. The beauty of this is that we can bridge circuitry using 2.5 volt logic to circuitry driven by 3.3 volt logic using this multi-banked I/O scheme. In our design, we load up both I/O banks for LVTTTL or LVCMOS33 operation by driving the VccIO1 and VccIO2 pins with 3.3 volts.

Theoretically, we could stop here. We have ample breadboard area, a powerful XC2C64A CPLD, sufficient XC2C64A CPLD and peripheral power, and a JTAG interface to program the XC2C64A. However, it's easier to simply patch in an LED or pushbutton than to mount and wire the parts onto the solderless breadboard every time you need them. So, let's add a byte's worth of LEDs and supporting current limit resistors along with a couple of simple pushbutton switches to the development board design. The addition of the LEDs and pushbuttons will allow us to easily code up two-input logic devices (AND gates, OR gates, etc.), provide the two-input logic device input stimulus using the

■ **SCREENSHOT 2.** Everything we need to bring the XC2C64A to life is included in this shot. However, it's probably a good idea to put the LEDs and pushbuttons down on the PCB instead of mounting them adhoc on the solderless breadboard.





pushbuttons, and view the two-input logic device output on one of the LEDs. Just in case we can't push the buttons fast enough or we need a steady clock source, let's also take this opportunity to add a low-power LTC6900 resistor-adjustable oscillator to the design. The LTC6900 is very easy to understand and just as easy to implement. If you need more details on the LTC6900, I suggest peeking at its datasheet. Once you see the LTC6900 datasheet, you'll know exactly what we're doing with it here. Screenshot 3 is a graphical representation of Photo 2 sans solderless breadboard. Use Schematic 1 to match up the electronic and electromechanical components with their pads on your

XC2C64A development board. You won't need any fancy SMT soldering equipment to assemble your board as all of the electronic and electromechanical components can be hand soldered with patience and a fine-tipped soldering iron. Note that I've mixed things up a bit on the component side. XC2C64A power supply bypass capacitors C9, C10, C11, and C12 are 0603 SMT devices. All of the resistors are 0805 SMT parts and the LEDs are all packaged as 1206 SMT. Use Digi-Key part number 493-2179-1 for filter capacitors C2, C3, C6, and C7 and Digi-Key part number SW416 for pushbutton switches A and B. I used LITEON LEDs on my development board. However, any surface-mount 1206 SMT LEDs will

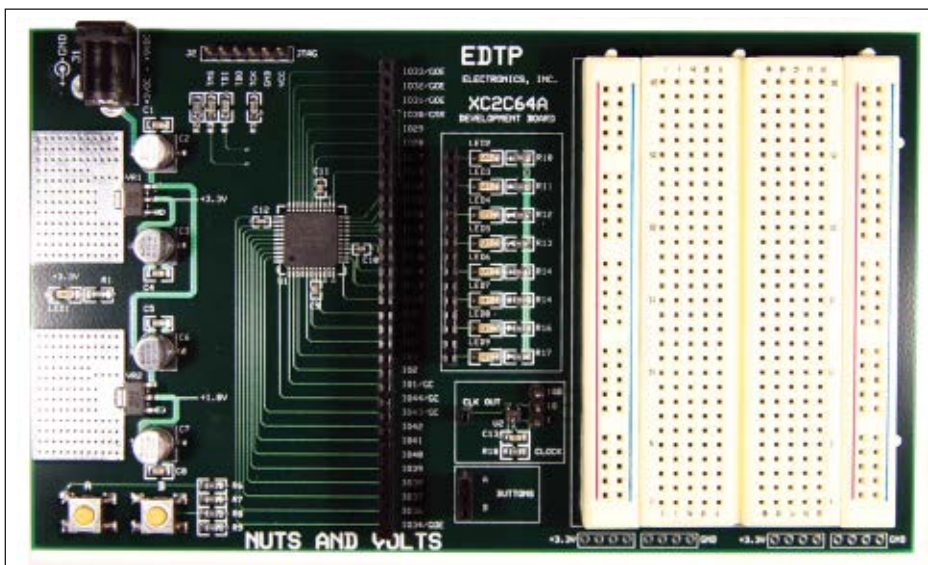
■ **SCREENSHOT 3.** With this layout, we can use the pair of pushbuttons as logic input levels for two-input logic devices. We also have enough LED support to see up to eight simultaneous output states. The LTC6900 is here to provide a clock that is much more stable than quickly pounding a pushbutton with a finger.

work. To use the current limit resistor values, just make sure the forward voltage of the LEDs you select is 2.2 volts. The idea is not to exceed 4 mA of current draw per LED. You can use LEDs with a 1.7 volt forward voltage as long as you adjust the current limit resistor accordingly. There are many LED calculators on the Internet that will show you how to determine the correct LED current limiting resistor value for a given LED current draw. One more construction note before we move on. All of the LED cathodes are aligned with the LED identifier on the development board.

TOOLING UP

The Xilinx CPLD software development environment is free. All you have to do is go to the Xilinx website and download a copy of ISE WebPACK. ISE WebPACK is much like Microchip's MPLAB. You can use WebPACK to create your CPLD source files, implement the CPLD design, and program the CPLD. The ISE WebPACK has its own set of editors, a fitter, and a compiler. The fitter does exactly what you think it does. It automatically "fits" your logic into the target XC2C64A hardware. Programming of the target CPLD is overseen by a component of WebPACK called iMPACT.

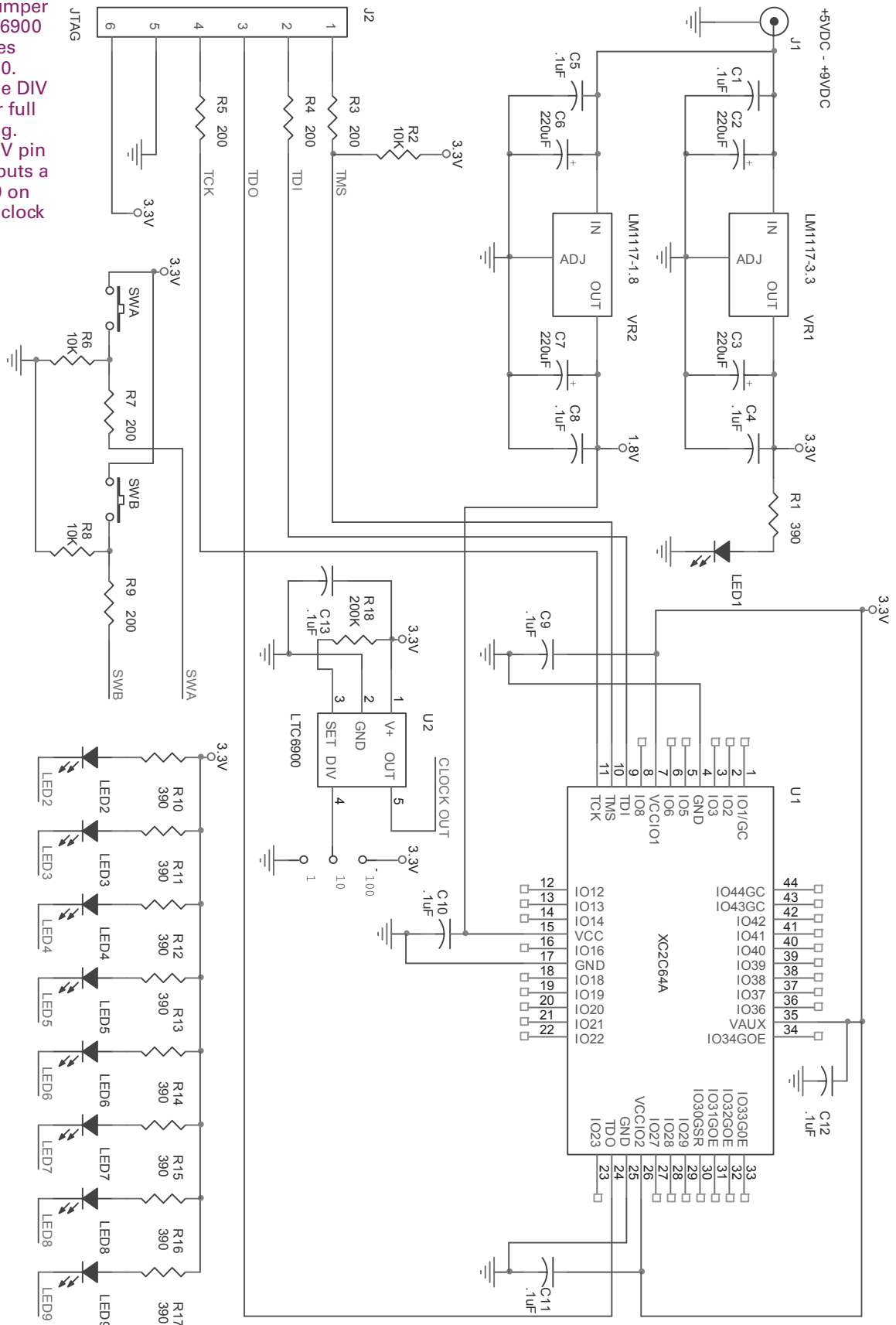
You will need the services of the Xilinx Platform Cable USB JTAG programming device (shown in Photo 3) when you're ready to put the logic you've designed using WebPACK into



■ **PHOTO 2.** Here is my version of the XC2C64A development board. You may choose to chuck the solderless breadboard for real holes in your design. There are no components here that can't be manually soldered onto the PCB. The female headers are Digi-Key part number 929974-01-36.

■ SCHEMATIC 1.

Leaving the jumper off of the LTC6900 DIV pin divides the clock by 10. Grounding the DIV pin allows for full speed clocking. Pulling the DIV pin to +3.3 volts puts a divisor of 100 on the outgoing clock pulses.



the XC2C64A. All you have to do is load up the ISE WebPACK on your PC to use the Platform Cable USB. Once your PC has recognized the Platform Cable USB hardware and installed the Platform Cable USB drivers, you need only match up the USB's JTAG leads to the development board's JTAG interface to bring the XC2C64A to life.

The Xilinx ISE WebPACK allows you to use the most popular CPLD programming languages. I've chosen to use ABEL (Advanced Boolean Expression Language). We could also use standardized HDLs (Hardware Description Languages) such as VHDL (VHSIC [Very High-Speed Integrated Circuits] Hardware Description Language) or Verilog to synthesize our XC2C64A logic. I selected ABEL as the preferred language for our XC2C64A project due to the fact that the ISE WebPACK contains a comprehensive built-in ABEL help library. Also, some very good ABEL tutorials can be had for a read or a download from our good friend, the Internet.

At this point, we have our very own XC2C64 Development Board, a Xilinx Platform Cable USB CPLD programmer, and Xilinx's ISE WebPACK. All we're lacking is some ABEL logic statements. So, let's go to class.

CPLD 201

If you've just picked up this magazine and this is your first read through, odds are that you don't have any XC2C64A hardware built up at this point in time. That's okay.

Load up the latest version of ISE WebPACK and follow along. Rather than walk you through every detail of building an XC2C64A project with WebPACK, I've supplied the entire set of project files we will be discussing with the XC2C64 download package. To experience XC2C64A development while reading this text, all you have to do is fire up ISE WebPACK and load the projects I've provided in the download package.

If you're not a seasoned CPLD user, you will need some learning curve time with ISE WebPACK. The best way to get up to speed with it is to simply load a project in and play it. Once you become familiar with WebPACK and you get your development board hardware online, you can burn the supplied applications into your XC2C64A and try them out on your XC2C64A hardware.

The most complex of logic ICs track their heritage back to basic forms of logic hardware such as AND, OR, NAND, and NOR gates. So, it is fitting that our very first XC2C64A code be that of a simple two-input AND gate. With that, let's put together some AND gate ABEL code.

BUILDING AN AND GATE

An ABEL-based code module begins with a module statement. The module statement consists of the module keyword (MODULE) followed by a module name. Let's call our module `and_gate`. This is what our AND gate ABEL code looks like at this point:

```
MODULE and_gate
```

Usually, declarations follow the module keyword and the module name. The keyword DECLARATIONS is implied when declarations follow the MODULE keyword-module name statement. However, ad hoc declarations can be made anywhere in the ABEL code module as long as the DECLARATIONS keyword precedes them. Let's use the classic method of declaring and define our AND gate inputs and output:

```
MODULE and_gate
```

```
inputA PIN;  
inputB PIN;  
outputC PIN istype 'com';
```

This looks a lot like C, doesn't it? Think about the code in terms of a physical AND gate. We have a pair of inputs and an output. The 'com' tells the compiler that the output pin is a result of a combinatorial operation. Combinatorial simply means that the result is derived from a combination of mathematical terms such as our AND gate inputs `inputA` and `inputB`.

We can also assign XC2C64A pin numbers to the input and output pins at this time. However, the pin numbers are automatically assigned in the XC2C64A implementation process and it is recommended to allow the automatic pin assignments to override your human pin assignment logic. The reasoning behind letting the software do the pin assignments lies in the software's ability to optimize the pin assignments to the logic that is generated inside of the XC2C64A's FBs. The Xilinx documentation also states that it took some really smart CPLD engineers 12 years to get to this point with the pin assignment automation. (That statement kinda



■ PHOTO 3. I originally purchased a JTAG programming cable, which required a parallel port interface. After discovering that my new laptop doesn't have a parallel printer interface, I got my hands on the Xilinx Platform Cable USB JTAG programming device you see here. You can get your own Platform Cable USB programming device from Digi-Key. The other end of the cable plugs pin-for-pin into the XC2C64 development board's JTAG interface.

reminds me of that who's-smart-caveman/psychiatrist commercial.) With that, let's see what happens if we leave the code as you see it here.

Now that we have the AND gate defined physically, let's define how the AND gate will work logically. First, we need to delimit this section of our code with an EQUATIONS keyword. Then, we enter the logic statement that defines AND logic:

```
MODULE and_gate

inputA PIN;
inputB PIN;
outputC PIN istype 'com';

EQUATIONS

outputC = inputA & inputB;

END
```

Again, if you've done some C coding, you're comfortable with what you see here. We're done with the coding and the END keyword closes us out of the module. If you use the ISE WebPACK New Project Wizard, you'll automatically get everything we just hand coded with the exception of the actual outputC equation and the 'istype 'com' extension.

Just for grins, let's add some test vectors to our AND gate code. We can do this by adding the test vector table directly to our ABEL module code or generating a separate test vector file. For clarity, let's put the test vectors in with our code for now. That way, you can see how the TEST_VECTORS keyword is used:

```
MODULE and_gate

inputA PIN;
inputB PIN;
outputC PIN istype 'com';

EQUATIONS

outputC = inputA & inputB;

TEST_VECTORS ([inputA,inputB] ->
outputC)

[0,0] -> 0;
[0,1] -> 0;
[1,0] -> 0;
[1,1] -> 1;

END
```

As you can see, we've simply laid out what we expect our AND gate to do given its input stimulus. The test vectors are optional and are used for simulation. ISE WebPACK has a simulation module that will allow you to view the output of each of the test vector table combinations.

I used the project wizard and added my particulars to the AND gate project we are working on right now. The wizard allowed me to select the type of CPLD to target, as well as provided an ABEL code skeleton for me to flesh out. If you're following along and have the ISE WebPACK editor page up on your PC, you'll see "Implement Design" in the Processes window. If we were to run the implementation process right now, we would get our XC2C64A AND gate pin assignments and the default I/O logic level. My default logic I/O level was set to LVCMOS18, which is not how our development board hardware is designed. So, before we run the design implementation, right click on "Implement Design" and take the Properties path. Choose the Fitting Category and scroll down noting your options. Set the "I/O voltage Standard" to LVTTTL. An alternate way to set the I/O voltage type is to create and edit a constraints file. You can do this from the Processes window in the User Constraints area. Note that you can also manually assign the XC2C64A pin numbers in the User Constraints area.

Implementation of the CPLD design entails compiling, translating, fitting, and generating a programming file. Run the "Implement Design" module and you'll receive a Fitter and Timing report at the end of the process. Go to the Pin List within the report and you'll find that inputA, inputB, and outputC are all assigned to XC2C64A pins. You should also see that the I/O levels of all of our AND gate pins is set to LVTTTL and the VccIO pin voltages are all set to 3.3 volts.

My fitter run assigned inputA to pin 37, inputB to pin 36, and outputC to pin 38. So, I jumped in

my AND gate, its stimulus, and output indicator on the XC2C64 development board in this manner:

```
Pushbutton A    -> pin 37 = inputA
Pushbutton B    -> pin 36 = inputB
LED 9           -> pin 38 = output
```

The "Generate Programming File" module in the Processes window controls the iMPACT module and the Platform Cable USB CPLD JTAG programmer. I attached the USB outputs to the JTAG interface and programmed the and_gate.jed file into the XC2C64A.

Note that the pushbutton switches produce a logical high when depressed. Thus, our initial input to our XC2C64A AND gate is a pair of logical lows. The LEDs are all installed to illuminate when the CPLD I/O pin is sinking current (logically low). Since our AND gate has a pair of low inputs, its output is also logically low, which results in the output indicator LED being illuminated. Both pushbuttons must be depressed to produce a logical high on the output of our AND gate, which extinguishes the LED.

A NAND gate is no more than an AND gate with a complemented output. Let's add a strategically placed NOT operator to build a NAND gate from our AND gate code. We'll also modify the test vectors to match up with our new logic:

```
MODULE nand_gate

inputA PIN;
inputB PIN;
outputC PIN istype 'com';

EQUATIONS

!outputC = inputA & inputB;

TEST_VECTORS ([inputA,inputB] ->
!outputC)

[0,0] -> 1;
[0,1] -> 1;
[1,0] -> 1;
[1,1] -> 0;

END
```

Now, the indicator LED is

SOURCES

Linear Technology
www.linear.com
LTC6900

Xilinx
www.xilinx.com
XC2C64A; XC2C32A; ISE WebPACK

extinguished until I depress both pushbuttons simultaneously. A pair of logical high inputs to a NAND gate results in a logically low output.

I suspect that you have a firm grip on the concepts I've presented thus far. So, let me throw out some operator bones for you:

OR Operator	#
XOR Operator	\$
XNOR Operator	!\$

where *X* means exclusive

With this operator information, I think you can put together all of the basic two-input logic gates with what you've seen thus far. So, let's move on and do some registered work.

LEARNING TO COUNT

The ABEL statements that follow should look familiar:

```
MODULE counter4
```

```
clk PIN;  
Q3,Q2,Q1,Q0 PIN istype 'reg';  
counter = [Q3,Q2,Q1,Q0];
```

```
EQUATIONS
```

```
counter.c = clk;
```

```
counter := counter + 1;  
END
```

Let's work the counter code from top down. Our counter module is named "counter4." Since this code is intended to synthesize a counter, we will need a clock to drive it. As you can see, I've declared a clock input PIN called "clk." Judging from the set of four outputs (Q3, Q2, Q1, Q0), our counter can count from zero to 15. I've assigned the four outputs to a set and named the set "counter." Note that the outputs are of type "reg," which means they are registered outputs. Registered outputs are associated with D flip-flops, which act as memory elements.

To use the clock input to move the counter bits, we must associate the clock with the counter. That's what I have done in the first ABEL statement in the EQUATIONS area of our counter code. The last ABEL statement before the END keyword is where all of the magic occurs. The

"**:=**" is an ABEL assignment operator and signifies that the transition of the clock signal forces the counter to increment itself by one.

After implementing the four-bit counter, the "clk" pin was assigned to IO43 on my XC2C64 development board. In this instance, my finger will be the clock stimulus. So, I jumpered pushbutton "A" to IO43. The counter outputs were assigned as IO38, IO37, IO36, and IO34, with IO38 being the most significant bit Q3 and IO34 representing the least significant bit Q0.

Sure enough, every depression of pushbutton A sent a low-to-high clock pulse via the clock pin (IO43) to the counter, and the LEDs I jumpered into the Q3-Q0 outputs danced to a binary counter tune. I noticed that sometimes the count would jump a count as I was releasing the pushbutton. To keep this from happening, I opened up the User Constraints module, selected Assign Package Pins, and turned on the Schmitt trigger input option for the clock pin. The counter then behaved as designed.

READY AND ABEL

The CoolRunner-II CPLDs are designed to consume very little power and I was able to use three AA batteries to power my XC2C64 development board. You can shave the battery count down to two by eliminating the 3.3 volt regulator. Don't get rid of the 1.8 volt regulator as the core voltage is an XC2C64A must-have.

Once you get your XC2C64 development board hardware up and running, check out the ABEL Reference that resides within the ISE WebPACK. There you will find many more ABEL example programs that you can run on your development board. After reading through the ABEL Reference, I guarantee that you will have no problem putting the XC2C64A into your Design Cycle. **NV**

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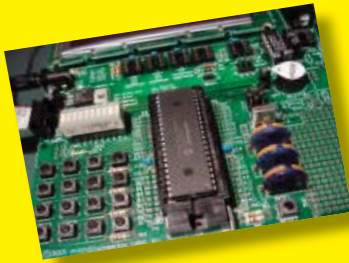
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GETTING STARTED WITH PICs

THE LATEST IN PROGRAMMING MICROCONTROLLERS

■ BY CHUCK HELLEBUYCK

GETTING STARTED WITH THE PICBASIC™ PRO COMPILER AND MPLAB® IDE

EMAIL FEEDBACK HAS MADE IT CLEAR THAT there are many who would like me to go back and cover how to get started, as the title of the column suggests. Though I've covered this in many previous columns, much has changed, and there are still some beginner topics I have not covered.

One area missed is how to set up and use Microchip's MPLAB IDE for developing your programs. If you write in assembly, C, or even microEngineering Labs' PICBASIC or PICBASIC PRO compilers, you can use the same MPLAB IDE. This is important to learn, especially for those who may graduate from a hobbyist programmer to a professional programmer.

All Microchip tools work directly with the MPLAB IDE. This includes the PICkit™ 2 Starter Kit (Part #DV164120), which I've covered in many articles before and I plan to use again as the hardware. For the software, I decided to keep it simple and inexpensive by using the sample version of the PICBASIC PRO compiler. This is the Basic language compiler I've written about many times before. After all, the BASIC acronym stands for "Beginner's All-purpose Symbolic Instruction Code." The keyword, here, is beginner.

The sample version of the PICBASIC PRO compiler is available as a free download from <http://melabs.com/pbpdemo.htm>, and the MPLAB IDE is available as a free download from www.microchip.com/mplab. The PICkit 2 Starter Package will cost you \$49.99 plus shipping if you purchase it from www.microchipdirect.com, but you can get it for the same price from Mouser or any other catalog source. The starter package includes a PIC16F690 microcontroller (MCU), so the free compiler and IDE downloads (plus the starter package) will give you everything you need to start programming. If you want to follow along with this article, you'll need these items.

INSTALLATION

The MPLAB IDE is a very powerful tool, with a lot of features. I will go over the essentials you'll need to know in order to get started quickly.

First, download the latest release of the MPLAB IDE.

As I write this article, version 8.02 is the latest. The MPLAB IDE download is a zip file that needs to be extracted into the directory of your choice. Once you have un-zipped the files, you will see a file named "Install_MPLAB_v8.02.exe." This is the installation setup file that you need to run. Follow the installation procedure and let it install at the default directory. This will put the MPLAB IDE and all of its components in the C:\Program Files\Microchip directory of your hard drive.

Next, download the PICBASIC PRO compiler demo version into a directory on your hard drive. This includes an installation file called "PBPDEMO3.EXE." Run this file and let it install at the default directory, which will be located at C:\PBPDEMO.

Next, download the file called "PBPlugins.bat." This file is strictly for the MPLAB-PBPRO connection. You can get this program from the <http://melabs.com/support/mplab.htm> page, along with details on how to use the PICBASIC PRO compiler with the MPLAB IDE. I'm telling you my way of doing this because I found one little glitch that I could not get around, and I suspect you'll run into the same thing. Run the PBPlugins.bat program. The instructions at microEngineering Labs' [mplab.htm](http://melabs.com/mplab.htm) Web page explain how to update the search path for the version of Microsoft Windows® you are running. Follow those instructions and update the search paths.

Next is the trick I recommend for getting around the glitch I ran into. Go to the C:\PBPDEMO directory and you will see three folders — INC, MCS, and SAMPLES. Add

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a new directory called PFILES. Now, go to the directory where the MPLAB IDE is stored (C:\Program Files\Microchip\MPASM Suite) and you will see a bunch of files that start with a “P” and end with an “.inc.” These include the files the compiler will look for and, for some reason, I could not get the MPLAB/PICBASIC PRO combination to find them. I even changed all the recommended path statements shown on microEngineering Labs’ MPLAB instruction page and it still could not find them. You can copy all those Pxxx.inc files into the PFILES directory that you made, but I suggest you just copy the list below:

P12F683.INC	P16F871.INC
P16F84.INC	P16F872.INC
P16F84A.INC	P16F873.INC
P16F627.INC	P16F873A.INC
P16F627A.INC	P16F874.INC
P16F628.INC	P16F874A.INC
P16F628A.INC	P16F876.INC
P16F688.INC	P16F876A.INC
P16F690.INC	P16F877.INC
P16F870.INC	P16F877A.INC

This list includes all the MCUs supported by the PICBASIC PRO sample version, which will make it easier to find these files later when we create a project in the MPLAB IDE.

SETUP

Now that everything is installed, we need to set up the MPLAB IDE to recognize the PICBASIC PRO compiler.

- 1) Start MPLAB and select “Set Language Tool Locations” under the Project menu.
- 2) Select the “PICBASIC PRO Toolsuite” name.
- 3) Use the browse button to select PBPDEMOW.EXE in the PBPDEMO directory where the PICBASIC PRO Demo version was installed.

Figure 1 shows the window you should see when you complete these steps. By choosing this path, you are indicating to the MPLAB IDE where the PICBASIC PRO compiler is located on your hard drive. Click on the OK button to accept this, and you are now ready to use the MPLAB IDE with the PICBASIC PRO demo version. If you have the full version of PICBASIC PRO, all the steps are the same except the PICBASIC PRO will be installed in the C:\PBP directory, and the file you select in the browse window is PBPW.EXE.

FIRST PROJECT

Now, you are ready to build your first project. In the MPLAB IDE, all the software files you create will be connected by a project structure. The easiest way to do this is to use the Project Wizard utility

in the MPLAB IDE. Click on the MPLAB Project menu and select the Project Wizard. You will be walked through several windows, which take you through the following steps:

- 1) *Select a device.* Choose the PIC16F690, as that is the part included in the PICKit 2 Starter Kit.
- 2) *Select a language tool suite.* Choose the PICBASIC PRO tool suite.
- 3) *Create a new project.* Use the browse button, and select the directory where you want to store the project and all of the files. I suggest you create it as close to C: as possible, to keep the path name short. Figure 2 shows my project, entitled “16F690_Blink” in the PBPCode directory that I created at the root.
- 4) *Add existing files to your project.* This is where you may select one of the PICBASIC PRO sample files that you wish to use or modify, or maybe an older file that you wrote. For this example, select the BLINK.BAS file in the PBPDEMO/SAMPLES directory. Highlight it, and then click on the Add>> button.

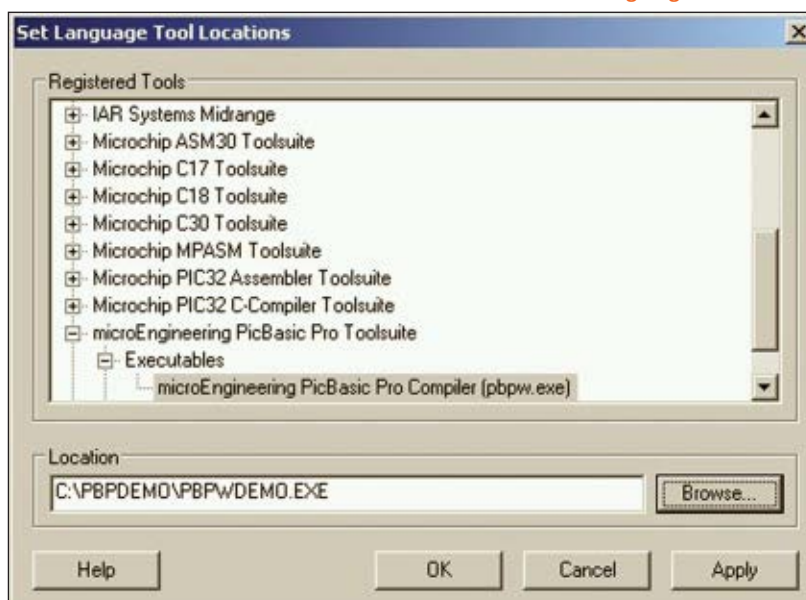
WAIT!!!! Don’t press the “Next” button, yet. Instead, use a trick that I found – change to the PFILES directory you created and select the P16F690.INC file. Then, click the Add>> button to add it to the project, as well. This will save you an error later. Finally, next to each file, you will see a big “A.” Click on that A until it changes to a C. This will automatically copy these files to your project directory. Figure 3 shows what your screen should look like.

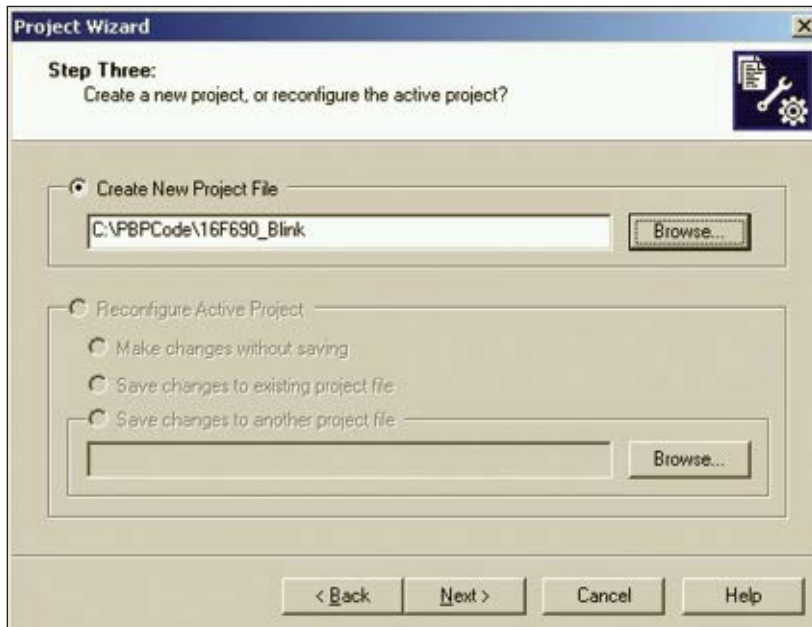
- 5) At this point, you’re done so click the FINISH button.

FIRST PROGRAM

Odds are that your MPLAB screen is now blank. If so,

■ FIGURE 1. PICBASIC PRO Language Selection.

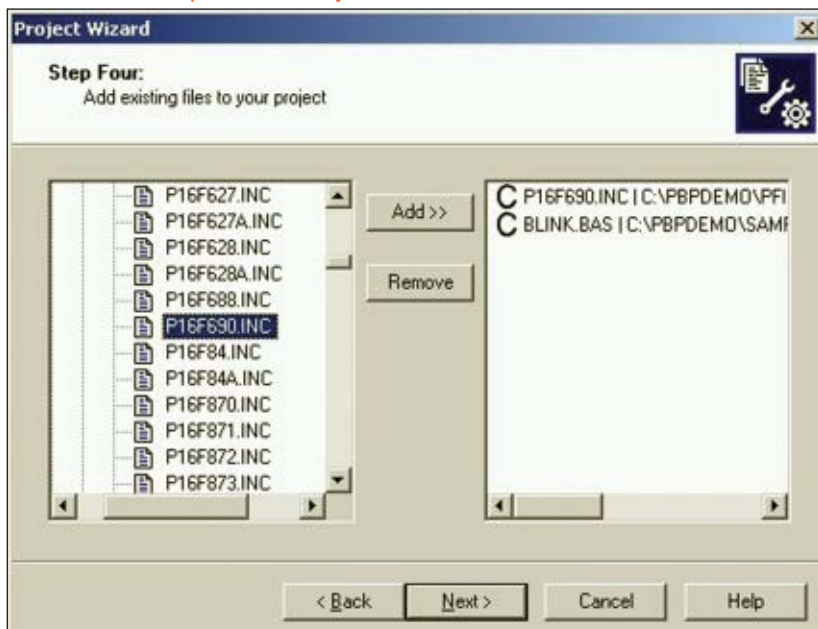




■ FIGURE 2. Step Three of Project Creation.

you need to click on the VIEW menu and select the PROJECT and OUTPUT windows. By clicking on these, a check mark will show up next to the menu selection, and the windows will appear in the MPLAB IDE with the project files shown in the Project window. The Output window will be blank. Figure 4 shows the final view. The BLINK.BAS and P16F690.INC files are listed and can be opened by double clicking on them. To actually run the BLINK.BAS file on the PIC16F690 MCU, we need to modify the basic file slightly. The sample file is written to work on the PORTB register, and we need to drive the PORTC pins. I modified the sample program to look like Listing 1. This is really a simple program, which makes it easier to prove out all the steps to get your first program

■ FIGURE 3. Step Four of Project Creation.



working. At the top of the program, though, are a few statements that might confuse the beginner. These are shown below:

```
ANSEL = 0      ` Initialize A/D ports off
CM1CON0 = 0    ` Initialize Comparator 1 off
CM2CON0 = 0    ` Initialize Coparator 2 off
```

These statements are required for using the PIC16F690 MCU's I/O as digital pins. The PIC16F690, like many other PIC MCUs, multiplexes the pin connections with other features. The PIC16F690 MCU has both Analog-to-Digital Converter (ADC) ports and comparators that share the actual pin connections with the digital I/O circuitry. To use the digital I/O pins, you must make sure the ADC and comparators are disconnected. For this project, we'll disconnect them by clearing the bits in these registers — Analog Select Register (ANSEL), Comparator 1 Control Register (CM1CON0), and Comparator 2 Control Register (CM2CON0).

The rest of the program is just a High, Low, and Pause loop that acts on the PORTC pin, RC0. This pin is connected to the DS1 LED on the PICKIT 2 starter board. By flipping the level on the RC0 pin from high to low with a pause in between and looping through that sequence multiple times, we make the LED flash.

Once the program is written, simply press the F10 button to compile the PICBASIC PRO file into a binary .hex file. If everything compiles without errors, you will see a "Build Succeeded" message in the output window. If you receive an error message, it will tell you in which line of code it is so that you can see what typo you may have accidentally made.

PROGRAMMING THE PIC16F690 MCU

Now that we have a binary .hex file, we need to load it into the PIC16F690 MCU so that it can run. For this, I will use the PICKIT 2 Starter Kit (see Figure 5), with the PICKIT 2 Programmer connected to the PC's USB port. The PICKIT 2 Programmer will then power the development board from the USB port and program the PIC16F690 MCU when inserted into its socket through the board's programming connector. Because the MCU is connected to the LEDs, switch, and potentiometer on the development board, we will use the In-Circuit Serial Programming™ feature to download the .hex file into the PIC16F690 MCU. This just means that you don't have to remove the MCU in order to program it.

To move forward from this point, we need to connect the PICKIT 2 Programmer to the USB port and then enable the programmer in the MPLAB IDE. We do so by selecting the PICKIT 2 from the "Programmer" menu at the top of the MPLAB screen (see Figure 6).

■ FIGURE 4. The MPLAB IDE Window.

The output window will gain a PICKit 2 tab and show the status of the PICKit 2 Programmer. You should see the following text displayed in the output window:

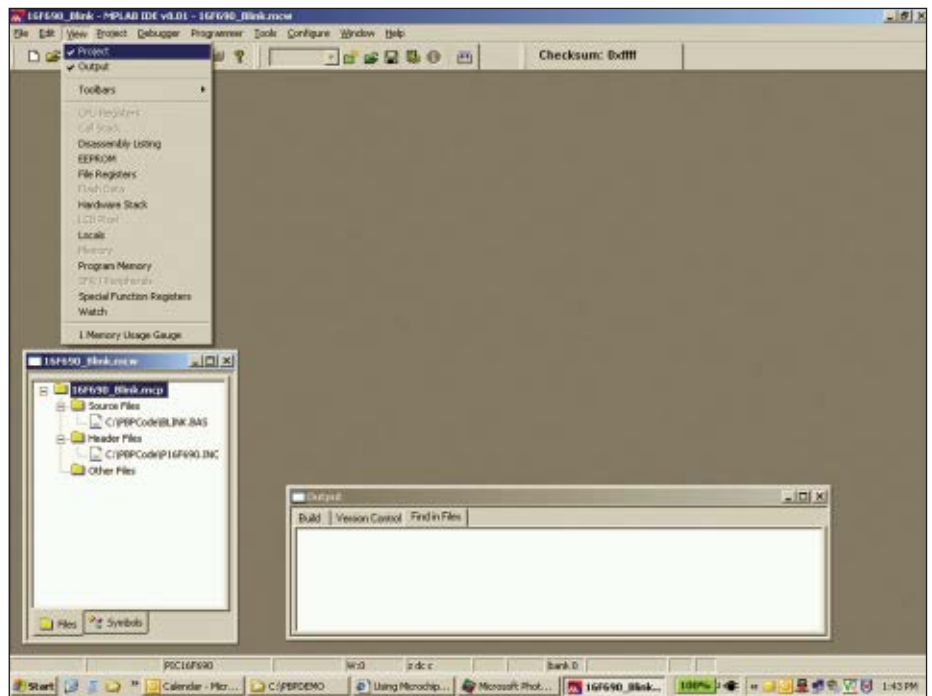
```
Found PICKit 2 - Operating System
Version 2.20.0
Target power not detected - Powering
from PICKit 2
PIC16F690 found (Rev 0x4)
PICKit 2 Ready
```

The message will indicate the operating system in the PICKit 2 Programmer, where the development board is receiving power from, and which MCU it detected. After this, a message stating the PICKit 2 is ready to program will be displayed. At the top right of the MPLAB window, the control buttons for the PICKit 2 Programmer should also appear, as shown in Figure 7. These buttons allow you to:

- 1) Program the complete part.
- 2) Read program memory.
- 3) Read EEPROM.
- 4) Verify that the program inside matches what you programmed.
- 5) Erase the complete device.
- 6) Verify that the complete device is erased.

You also have control over the MCLR reset line on the MCU, which are the rising- and falling-edge icons. By clicking on the rising-edge icon, you allow the PIC16F690 MCU to run the program. The last icon is a miniature PICKit 2, which just allows you to re-check the status of the programmer.

To load the BLINK.hex file into the PIC16F690 MCU, simply click on the first icon button and the PICKit 2 Programmer will handle the rest. You will see the status in the PICKit 2 output window. It will first erase the



MCU, and then program and verify it. After this, the programmer is ready to run. Click on the rising-edge button to bring MCLR to VDD. The LED should start to flash.

ERRORS

To get through all of this without errors is a very good start. However, chances are you might see a few errors, or get all the way to the end and find that the LED does not flash. I'll try to cover a few of the more common errors that the beginner might run into. The first involves the PICBASIC PRO compiler and the MPLAB IDE/Windows structure. For some reason, no matter how I changed the path structure in Windows or reset things in the MPLAB setup screens, I would encounter the error shown in Figure 8 when I first tried to run the PICBASIC PRO compiler in the MPLAB IDE.

In fact, I received a whole list of errors that started with the line "Cannot open file ... P16F690.INC." This is

■ FIGURE 5. PICKit 2 Starter Kit.



LISTING 1: BLINK.BAS Sample Program

```
\ Example program from manual to blink and LED connected
\ to PORTC.0 about once a second.
```

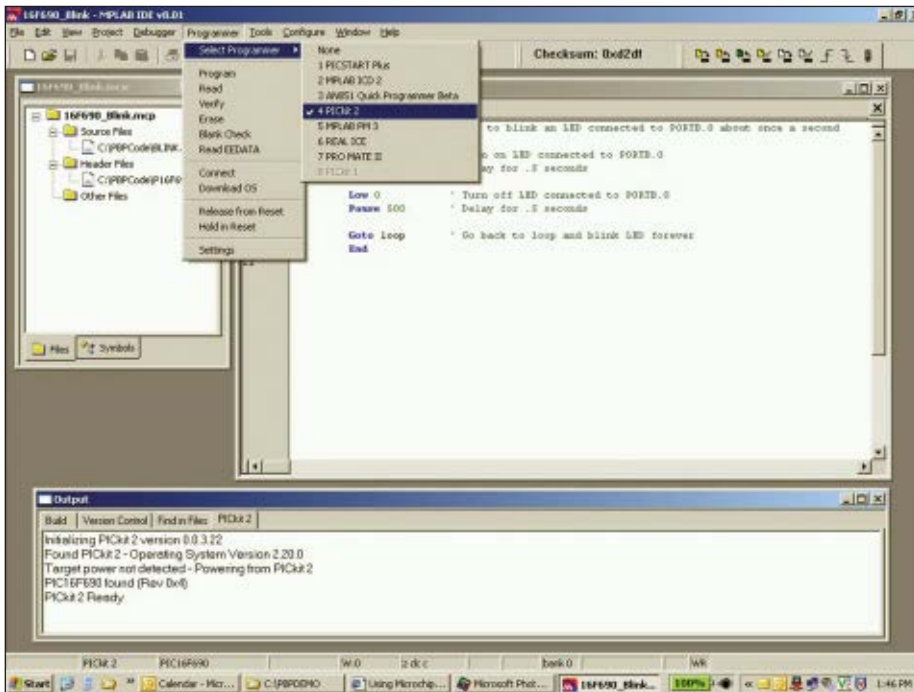
```
ANSEL = 0           \ Initialize A/D ports off
CM1CON0 = 0         \ Initialize Comparator1 off
CM2CON0 = 0         \ Initialize Comparator2 off

loop:  High PORTC.0   \ Turn on LED connected to PORTC.0
      Pause 500      \ Delay for 5 seconds

      Low PORTC.0    \ Turn off LED connected to PORTC.0
      Pause 500      \ Delay for 5 seconds

      Goto loop      \ Loop back and blink LED forever

End
```

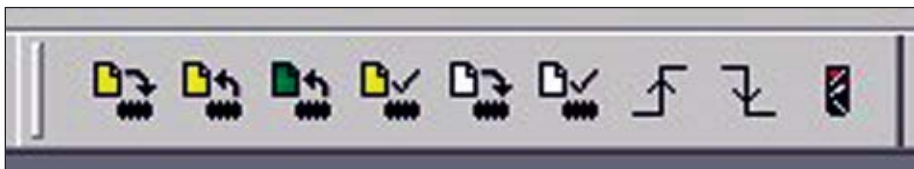



■ FIGURE 6. PICkit 2 Programmer Selection.

MCU you are using. In this case, the file is named 16F690.inc. You will find it in the PBP or PBPDEMO directory, where you installed the PICBASIC PRO compiler. The file will contain a `_config` line, like the example below:

```
_config _INTRC_OSC_NOCLKOUT & _WDT_ON
& _MCLRE_ON & _CP_OFF
```

This line in the 16F690.inc file is where the PICBASIC PRO compiler gets the information on how to set the configuration bits inside the .hex file. In this example, the internal RC oscillator is used as the system clock. This is what I recommend for the PIC16F690 MCU, but you can change it to an external oscillator if you need more accuracy. For the beginner, I would not worry about all of this — just know that it exists. However, if you find that your LED does not flash, then you might want to make sure the settings are adequate for what you need. For example, if you are developing on a



■ FIGURE 7. PICkit 2 Control Buttons.

board that has an external 20 MHz crystal and you keep finding that the program is running slow, you might have the internal oscillator set up in the configuration.

One of the biggest errors I've seen with beginners is the exact opposite—they think they are using the internal oscillator, but the configuration is set to run from an external oscillator (i.e., `_XT_OSC`). The MCU won't run without a clock.

why I suggest you use the project wizard the first time you create a project, and include the P file for the part you are using to prevent this error from occurring. If you forget, you can add a copy of the P file later, but it has to be put into the same directory as the .bas file you created.

Another beginner error that crops up often involves the configuration settings. Outside the structure of your program, the PIC16F690 MCU has certain bits that are set at program time to control the watchdog timer, the power-up timer, the oscillator selection, and more. All of the options for the part can be seen by clicking on the `Configure>Configuration bits` menu selection in the MPLAB IDE (see Figure 9). You can manually select the options, or click on the little box in the upper-left corner to allow the compiler to set these in code.

I recommend that you set the options in code, because they will then be embedded in the .hex file used to program the MCU. The PICBASIC PRO compiler puts that configuration setup in a separate file that it calls at compile time. The setup will be in an .inc file that has the name of the

board that has an external 20 MHz crystal and you keep finding that the program is running slow, you might have the internal oscillator set up in the configuration.

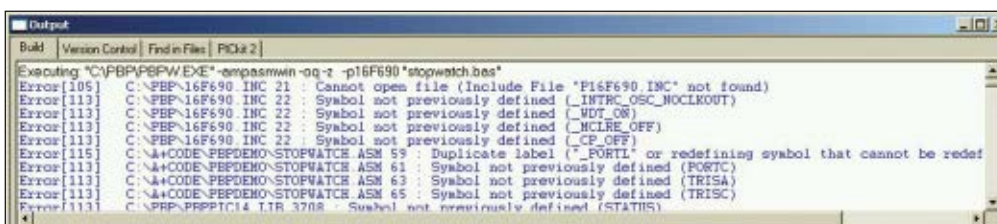
One of the biggest errors I've seen with beginners is the exact opposite—they think they are using the internal oscillator, but the configuration is set to run from an external oscillator (i.e., `_XT_OSC`). The MCU won't run without a clock.

CONCLUSION

I covered a lot of ground in this article. However, if you use this setup and get that first LED to blink, you are ready to start creating more software programs without having to worry about all of the hardware setup connections. What I suggest you do is modify the PAUSE command value to get the LED to flash faster or slower. Then, perhaps try to duplicate the code and get it to flash a second LED. If you alternate the high and low commands, you can make the LEDs flash back and forth, like lights at a railroad crossing.

Some readers have shared that they think my column is good, but they sometimes get lost trying to follow along.

They feel I'm writing to a bunch of engineers, rather than to hobbyists. I understand this completely, however this is a normal reaction as my subject matter can seem complicated to



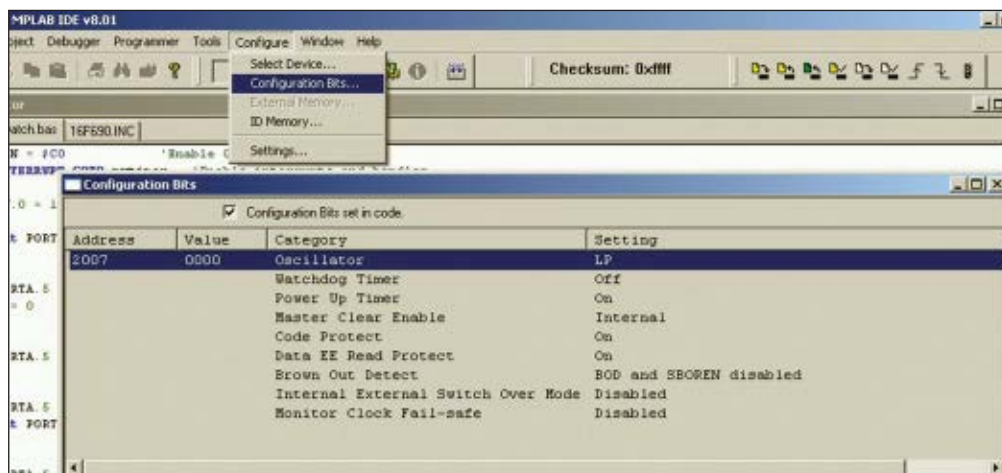
■ FIGURE 8. Compiler Error.

■ FIGURE 9. Configuration Menu.

people who are just getting started with MCUs. Once you get an LED to flash, the fear subsides and you begin to understand things much easier. You can go back and re-read my previous columns, and suddenly all of the complicated stuff becomes easier.

Another problem is that some readers are familiar with using little Basic modules that have all the inner details hidden from the user, in order to make things easier. You pay for that, though, by not having the ability to use all the features an MCU can offer. Many times, you sacrifice speed and memory space for simplicity, not to mention paying a lot more for the MCU. This will seem like a leap at first but, trust me, it's not that tough.

On the other side of the fence, I receive other comments stating that I often use too simple of an example — such as flashing an LED — to show how to get started (as I've done in this column). I will cover more complicated projects using this same MPLAB IDE, PICBASIC PRO compiler (sample version), and PICKit 2 Starter Kit setup in future columns. The idea I have with this new approach to the beginner path is to use a common, but powerful and professional set of development tools and software to create a step-by-step guide to getting started in programming. I plan to use this same setup in many future columns to remain consistent. I hope you'll continue to tune in. After readers get more comfortable with the PICBASIC PRO compiler, they can then advance to the full version or possibly convert to the C language. By then, my *Beginner's Guide to Embedded C Programming*



book should be in print, and I can help you down that path.

Please send your feedback on this particular article to me, so that I can determine how successful you were in getting all of this to work. My email address is chuck@elproducts.com. I try to answer all emails, but I sometimes find messages from readers caught in my spam filter. Please write "Nuts & Volts" or "N&V" in the subject line to help me find your email. Your feedback will enable me to explain the subject matter of my columns in more complete ways (there is only so much I can fit into a few *Nuts & Volts* pages).

Additionally, if you get a chance, check out my new web-site dedicated to my **books-www.elproducts.com**. If you are a fan of my modules and other hardware, you can now buy them from my friends at **www.beginnerelectronics.com**.

I hope you tune in to my next column (July '08 issue), where I'll show you how to use an ADC to read the potentiometer on the PICKit 2 development board. **NV**

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■ Chuck Hellebuyck can be reached at chuck@elproducts.com.

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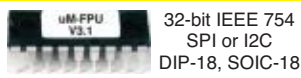
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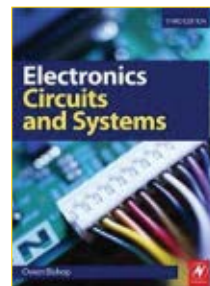
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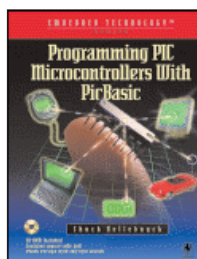
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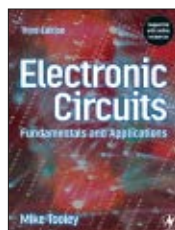
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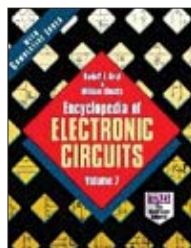


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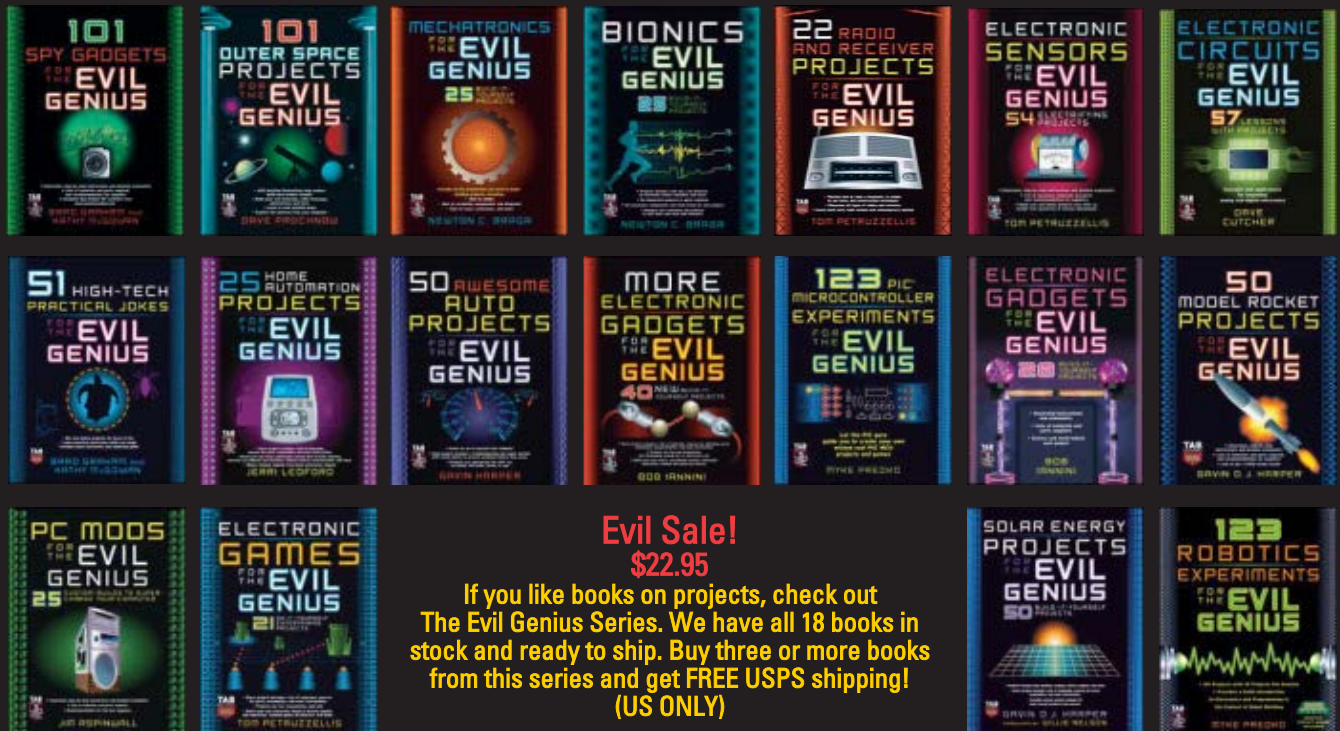
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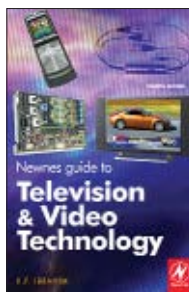
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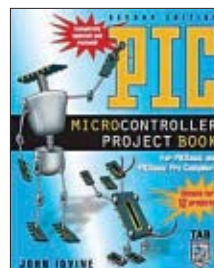
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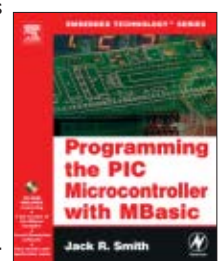
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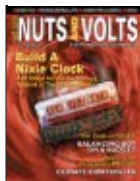
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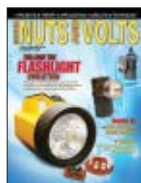
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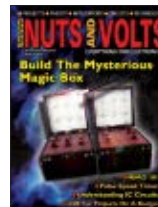
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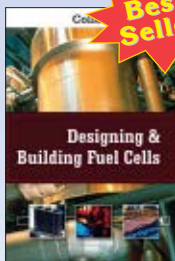


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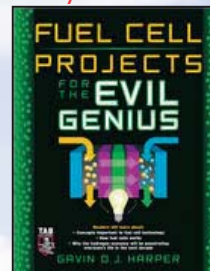
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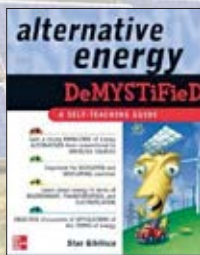
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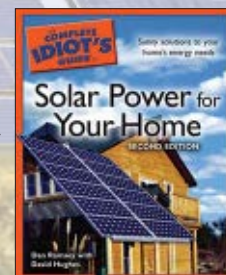
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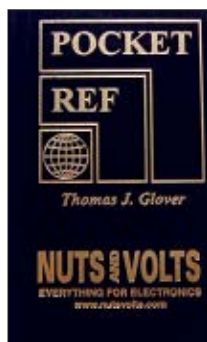
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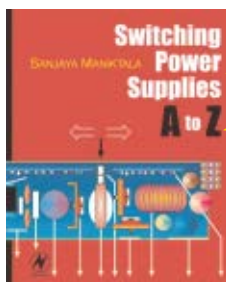
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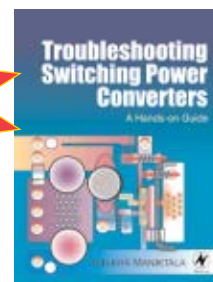
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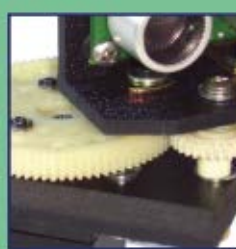


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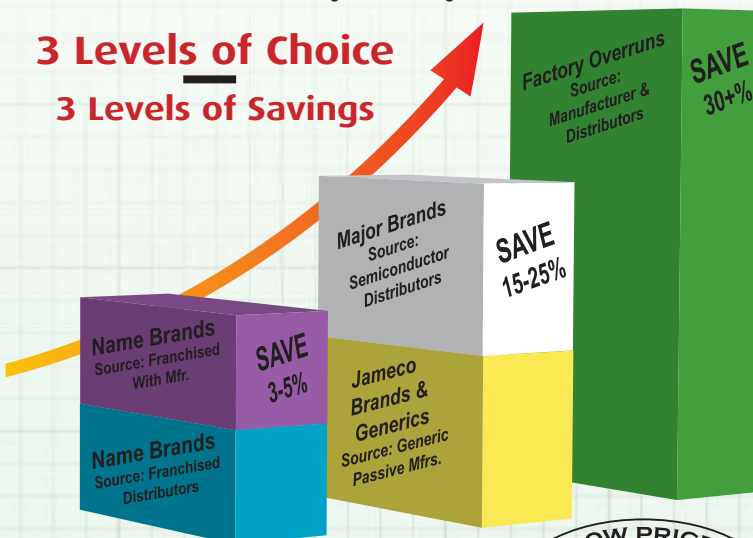
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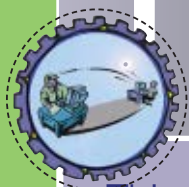
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TECH



FORUM

This is a READER-TO-READER Column.

All questions *AND* answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and **NO GUARANTEES WHATSOEVER** are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

All questions and answers should be sent by email to forum@nutsvolts.com All *diagrams* should be computer generated and sent with your submission as an attachment.

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To be considered, all questions should relate to one or more of the following:

- ① Circuit Design
- ② Electronic Theory
- ③ Problem Solving
- ④ Other Similar Topics

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>>> QUESTIONS

I'd like to use a white LED to light up a wall-mounted keepsake box (like a picture frame, but thicker). It should light with a pushbutton and turn itself off after an hour or two and use as little current as possible when off.

#5081

Joe R.
via email

I have two questions about the IBM Ideascan model 0275011 used on the parallel port (printer port):

1. What is the wavelength of the light tube?

2. What are the control codes, e.g., light on/off, move, stop, speed, etc.

#5082

Paul Weijers
Lachine, QC Canada

Has anyone hacked a digital camera and installed the sensor and minimum circuits into an old film camera like an old Nikon F or Leica M2 or M3? I've seen astrophotog guys hack digital Canon EOS D30 and Rebel to remove the IR filter for IR photography ... I don't know which electronics I can safely clip out of the digital donor. (There are film camera nuts out there that would die to see this done.)

#5083

George Kase
via email

I'm looking for an affordable (US) PCB MFG who specializes in prototype

quantities (<100) of COB (chip on board) from DIE that I provide. I need a company who can lead-attach the DIE and epoxy-seal it, forming a COB PCB.

#5084

Charlie Van Dien
Port Saint Lucie, FL

>>> ANSWERS

[#3082 - March 2008]

Can someone explain how the digital-to-analog TV converters will work?

Prior to February 2009, US domestic over-the-air television stations transmit an analog signal called NTSC which has remained the same since 1953. After that date, television stations will transmit a digital data stream over the air and analog TV sets will require a converter, which will be subsidized to \$40 by a coupon from the Federal government.

Inside the converter box, a tuner — similar to the existing analog RF front end of a TV set — will select channels and pass the 44 MHz IF to an analog-to-digital converter. The resulting digital data is decoded by an MPEG2-HD circuit and stored in digital memory, which is needed to reconstruct the original image as the compressed data arrives. The format of the data is determined by the program source material and can be any standard from SDTV (Standard Definition TV formerly known as NTSC) at 4:3 aspect 525i60,

all the way up to HDTV in 16:9 aspect 1080p60 high definition images — as long as the data fits in the 19.4 Mbits data stream of a digital TV channel.

Because the converter box is going to feed an SDTV analog output, the data is down-converted and changed to analog video at the old NTSC rates, regardless of the original material format. Better converters will allow scaling of the image (zoom, stretch, normal), similar to a digital cable box or DVD player.

This new analog NTSC signal is fed directly by cable to a TV set with AV jacks, and is also available as an RF signal on channel 3 or 4 (similar to first generation home VCRs). Audio from the MPEG2-HD stream is decoded to analog stereo for AV jacks, and also added as mono to the RF output. Closed caption data is stripped from the MPEG2-HD stream, reformatted, and added to the NTSC output to retain the closed caption service (where available in the source material).

Much of the digital processing is done in VLSI ICs and memory chips, making this sophisticated digital box small and affordable. It will come with yet another remote control, and your old analog TV will be left on Channel 3 or 4, or connected via the AV input (that provides slightly better images). The old analog TV will not be HD so a new set is required for true HD display.

**Peter Stonard
Campbell, CA**

[#3083 - March 2008]

How can a functional, small generator with voltage regulation be built to operate on a bicycle?

If you are talking about using an already-made tire driven "bicycle generator" that was used to power incandescent headlights and tail lights ... first of all, they are alternators (the French word for them is l'alternateur). They put out variable frequency (higher rotation speed = higher frequency, voltage, and current). My initial experience in the 1960s using a steel German made one was I would burn out my headlight bulb as a bicycle speed of 20 mph was approached.

A cheap fix was an output

"generator," fed into the AC side of four discrete diode bridge rectifiers. I mounted the generator on a varnish soaked hunk of masonite clamped to the left front fender brace to keep it electrically isolated from the bike frame as one side of its windings were connected to its metal body. Then, a dime-a-dozen stud mount 6.3V zener diode was connected to the positive output of the bridge rectifier along with one side of the headlight bulb and was used to divert away any voltage over 6.3 volts from the headlight bulb.

The other side of this 30 amp zener (they were rated in amps not watts back then) was fed into a second six-volt light bulb as the high beam in my previously battery powered high/low beam, two bulb headlight, instead of being fed directly to negative ground or through a power wasting resistor to ground. (Later, I reconnected the batteries through a normally closed reed switch with a coil of wire wound on a nail in series with that headlight bulb next to it, so the light stayed on when I stopped moving.)

That second bulb began burning out at 30 mph, so I added a second identical zener between the first zener and second bulb connection and fed it into a third bulb in a second headlight aimed further up the road for even better high speed visibility. The other side of that bulb was connected to common negative. I also used that connection to charge radio batteries, etc. The fewer parts, the higher the reliability. The more over-rated the parts, the higher the reliability, although 30 amp zeners were way overkill, but the price was right. Ten amp zeners worked fine and didn't even get warm except from sunlight. Since then, I've made prettier ones with smaller, more modern components, but it's the same basic circuit. It works on internal hub generators and rim/spoke mounted magnet types, as well.

If you are building your own generating unit, my recommendations are: avoid brushes, stick with rotating magnets. I used small "washer" shaped barium-samarium magnets recently with non-ferrous stainless steel shafts made out of a bolt and two pieces of

20 gauge steel sheet metal, cut into appropriate sized equilateral triangles with a hole drilled in the center, mounted on the shaft at each end of the three-magnet stack. We bent the triangle "points" over to form alternating poles to energize the stator winding. The stator winding and housing were the fields and housing from a non-permanent magnet 20 VDC motor (an AC motor's fields would probably have been better). We replaced the "bronze bushing" bearings with the roller bearing assemblies scrounged out of an old Lear Jet eight-track deck where they held the flywheel/capstain assembly. I used the same zener circuit with 9V zeners instead of 6.3V to charge computer batteries and LED light batteries (in that order of priority). (Max. total output at 15 mph downhill was 18.9 VDC at 2.65 amps and the unit provided the constant light braking needed to stop downhill over-acceleration.) My "washer" shaped magnets were north magnetic on one face and south on the other. Balancing was done by trimming "points" at or slightly past bends on bent triangles. These modern magnets are wonderful stuff! A stationary stator coil and stationary magnet system can also be used with a rotating magnetism distributor similar to some commercial brushless alternators (Neihoff, for example), only smaller.

**Bob Kennet
Everett, WA**

[#2081 - February 2008]

I'm learning electronics on a self study basis. My main book has a brief section on impedance matching. The key idea is that power transference will be at a maximum when the source impedance is equal to the load impedance. It doesn't do a very good job demonstrating the math. I need a more detailed explanation.

#1 Many electronics textbooks describe the so-called "maximum power transfer theorem." The idea is that you get the maximum amount of power into a load when the load impedance is equal to the impedance of the source. You can easily prove it

to yourself by using a spreadsheet simulation — pick a particular source voltage and resistance, and then calculate the power into load resistors of various values (it's a lot easier than using calculus). You'll get the most power if the load is equal to the source resistance. It's a nice thing to know, but useless and potentially even dangerous. Don't waste time on it.

The problem is that, if the source and load resistances are equal, then they also use up the same amount of power (since they are in series and have the same current, voltage, and resistance), which drastically increases the heat dissipation in the source. This automatically means that half of your power is used up in the source, so you have a maximum of 50% efficiency. Look at it another way — connecting such a load drops the voltage in half, because the source resistance and load resistance get the same voltage. Imagine what your electric utility would say if you dropped their voltage from 120 to 60 volts every time you turned on an appliance!

There are a few places where this is done. For example, a solar cell installation where you want to get as much power out of the sun as possible. In this case, you might load it down heavily enough to drop the open-circuit voltage in half. Or, in starting a car, when the battery voltage might drop from 12 down to perhaps 8 or 9 volts (but hopefully not as low as 6 volts) when you energize the starter. But most other places we stay far away from loading down a source that heavily, even for just a short time.

By the way, maximum power transfer is not the same as impedance matching. We often match source and load impedances, but for other reasons. In transmission lines, we do it to avoid reflections. There are also cases where we think we're matching impedances, but we aren't. For example, when you connect an eight-ohm speaker to an amplifier output labeled eight ohms, we're not matching impedances at all. An eight-ohm amp output is labeled that way to tell us what kind of speaker to use, not because its output impedance is really eight ohms — in most cases, the

actual output impedance of the amp is only a tenth or even a twentieth of the labeled value. This improves the transient response of the speaker (look up Damping Factor on the web for the full story), as well as the efficiency. So, don't get hung up on maximum power transfer. It's not as practical as teachers, professors, and book authors make it out to be.

Peter Stark
Mount Kisco, NY

#2 An analytical solution of the problem requires calculus. However, an understanding can be achieved by considering that all parts of the circuit are held constant except the load resistance (let us confine our analysis to resistance only for simplicity). If the load resistance is zero, the current will be maximum but there will be no voltage drop across the load and thus no power developed in the load. If the load resistance is infinite, the voltage across the load will be maximum but there will be no current and thus no power developed in the load. Obviously, the answer lies somewhere between these extremes. You can make a graph by calculating the power in the load for various load resistances and plotting the power versus the load resistance. The maximum value of the power will correspond to a load resistance equal to the resistance of the rest of the circuit.

Michael S. La Moreaux
Ann Arbor, MI

#3 Let's model the circuit by the impedance, Z , of the source and let's use Z plus Zx for the impedance of the load. Consider all of these elements in series. We can assume that there is a constant voltage source across Z_{in} and it's impressed also across the impedance of the load which is $Z+Zx$.

$$Z_{source} = Z$$

$$Z_{load} = Z+Zx$$

Set the power of the source equal to the power to the load, where $P = V^2/R$.

$$P_{in} = V^2/Z$$

$$P_{out} = V^2/(Z+Zx)$$

Since the power in must equal power out for maximum transfer — $P_{in}=P_{out}$ — thus:

$$V^2/R = V^2/(Z+Zx)$$

V is a constant, Z is a constant, so divide by V^2

$$1/Z=1/(Z+Zx)$$

$$Z = Z + Zx$$

$$0 = Zx$$

Therefore, the source and load impedances must be the same.

Ron Dozier
Wilmington, DE

#4 Here's an explanation of the Maximum Power Transfer question. Let's assume we have a voltage source of voltage, V , with a fixed internal impedance of R_S , as shown in Figure 1. We can adjust the load impedance R_L , and the question is how to adjust it so as to maximize the power transferred to R_L . Now, $P = IV_L$. Since the load is in series with the source, the current is the same throughout the loop, $I = V/(R_S+R_L)$, per Ohm's Law. But the voltage seen by R_L is $V_L = VR_L/(R_S + R_L)$, as a result of the voltage divider. So, the power dissipated in R_L is

$$P = [V/(R_S+R_L)][VR_L/(R_S + R_L)] \text{ or}$$

$$P = R_L V^2 / (R_S^2 + 2R_S R_L + R_L^2)$$

Now we can see that as R_L approaches zero, the power transferred will approach zero because of the R_L factor in the numerator. But as R_L becomes very large, the R_L^2 term in the denominator will take over, also causing an approach to zero power transfer. In between these two cases of minimal power lies a maximum, which turns out to be when $R_L = R_S$. This can be demonstrated by selecting different values for R_L . A plot is shown in Figure 2, assuming $V = 1$ volt and $R_S = 50\Omega$.

Bill Faris
Murray, UT

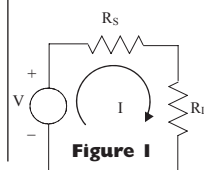


Figure 1

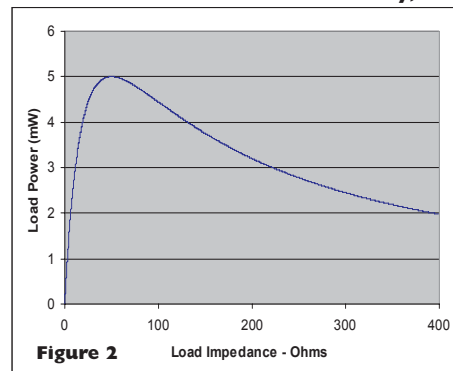


Figure 2



AMATEUR RADIO AND TV

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BATTERIES/ CHARGERS

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Our Premium All in One Repairing System

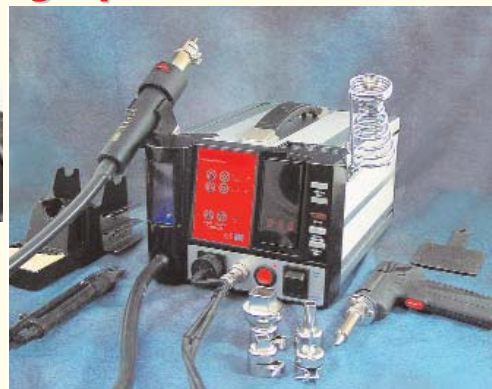
- All in One system. Combines the function of a Hot Air Gun, a Soldering Iron and a Desoldering Gun.
- Microprocessor controlled ESD safe unit. All digital display of hot air temperature, soldering iron temperature, desoldering gun temperature and air pressure with touch type panel controls.
- The desoldering tool comes with zero crossing circuitry preventing electrical surges and is equipped with air cylinder type strong suction vacuum pump.
- The 24V soldering iron is compatible with the compound tip design by connecting the ceramic heater, sensor, control unit and tip as one. Designed for efficiency. Replacement of tips with easy slip in/out method.
- Compatible with various type of air nozzles.
- Compatible with different kinds of tips.
- Full compliment of nozzles & tips are available.
- Use with lead-free or standard solder.

**FREE CSI486
Smoke Filter (a \$27.99 value)
with the purchase of a
CSI-9000**

**Item#
CSI-9000**

**Only
\$249.00**

Details at Web Site > Soldering & Rework > Hot Air Rework



www.CircuitSpecialists.com

Circuit Specialists Soldering Station w/Ceramic Element & Seperate Solder Stand

\$39.95!

- Ceramic heating element for more accurate temp control
- Temp control knob in F(392° to 896°) & C(200° to 489°)
- 3-prong grounded power cord/static safe tip
- Seperate heavy duty iron stand
- Replaceable iron/easy disconnect
- Extra tips etc. shown at web site

Item #

CSI-STATION1A



Rapid Heat Up!

Also Available w/Digital Display & MicroProcessor Controller

\$51.95

**Item #
CSI-STATION2A**
Details at Web Site



**SMD Hot Tweezer
Adaptor Fits CSI
Stations 1A & 2A,
and CSI906**

\$29.00

**Item #
CSITWZ-STATION**



> Soldering & Rework > Soldering Stations

Variable Temperature Hot Air Gun w/Heat Shrink

- 2000 watt output
- Special handle allows the heat gun to stand upright
- Choice of two speed & temperature settings: Low provides 51° - 580°C (123.8° - 1076°F) and High provides 57° - 650°C (134.6° - 1202°F)
- 5-1/2' Power Cord with secure-lock plug

**This excellent quality hot air gun is bundled
with a total of 68' of Heat Shrink...FREE!**

This is a \$15.57 value included at no extra cost!



NEW!

Details at Web Site > Electronic Parts & General Supplies > Hand Tools

Item #: HE-2000TK Now Only \$22.95

Dual Output DC Bench Power Supplies

High stability digital read-out bench power supplies featuring constant voltage and current outputs. Short-circuit and current limiting protection is provided. SMT PC boards and a built-in cooling fan help ensure reliable performance and long life.

- Source Effect: $5 \times 10^{-4} = 2\text{mV}$
- Load Effect: $5 \times 10^{-4} = 2\text{mV}$
- Ripple Coefficient: $< 250\mu\text{V}$
- Stepped Current: 30mA +/- 1mA

**HOT
ITEM!**

All 3 Models have a 1A/5VDC Fixed Output on the rear panel

CSI3003X-5: 0-30V/0-3amp 1-4: \$105.95 5+: \$99.50

CSI5003X5: 0-50V/0-3amp 1-4: \$114.95 5+: \$109.00

CSI3005X5: 0-30V/0-5amp 1-4: \$119.00 5+: \$114.00

Details at Web Site > Power Supplies > Bench Power Supplies

**As Low As
\$99.50!**



Programmable DC Power Supplies

The CSI 3600 Series Programmable DC Power Supplies are equipped with a back-lit LCD display, number keypad and a rotary code switch for ease of use & quick programming. Voltage, Current & Power can all be displayed on the LCD or computer screen (with optional RS-232 interface module). It can be operated at constant current mode, constant voltage mode & constant power mode. It also can be set with maximum limits for current & power output. Ideal instruments for scientific research, educational labs or any application requiring a sophisticated DC-power source.



Model	CSI3644A	CSI3645A	CSI3646A
DC Voltage	0-18V	0-36V	0-72V
DC Current	5A	3A	1.5A
Power (max)	90W	108W	108W

**Only
\$199.00
Each!**

Details at Web Site

> Power Supplies > Bench Power Supplies

ESD Safe CPU Controlled SMD Hot Air Rework Station

The heater and air control system are built-in and adjusted by the simple touch of the front keypad for precise settings.

Temperature range is from 100°C to 480°C / 212°F to 896°F, and the entire unit will enter a temperature drop state after 15 minutes of non-use for safety and to eliminate excessive wear.



**Item#
CSI825A++**

- CPU Controlled
- Built-in Vacuum System
- Temperature Range: 100°C to 480°C / 212°F to 896°F
- 15-Minute Stand-By temperature "sleep" mode
- Power: 110/120 VAC, 320 W maximum

Details at Web Site

> Soldering & Rework > Hot Air Rework

**Only
\$159.00!**

Triple Output Bench Power Supplies

with Large LCD Displays

- Output: 0-30VDC x 2 @ 3 or 5 Amps & 1ea. fixed output @ 5VDC@3A
- Source Effect: $5 \times 10^{-4} = 2\text{mV}$
- Load Effect: $5 \times 10^{-4} = 2\text{mV}$
- Ripple Coefficient: $< 250\mu\text{V}$
- Stepped Current: 30mA +/- 1mA
- Input Voltage: 110VAC



CSI3003X3: 0-30VDCx2 @3A \$188.00 5+: \$183.00

CSI3005XIII: 0-30VDCx2 @5A \$249.00 5+: \$234.00

Details at Web Site > Power Supplies > Bench Power Supplies

CLOSEOUTS !

Limited To Stock On Hand

Sorry....No BackOrders

12-28VDC, 283 CFM Axial Fan



- CFM: 282.5
- Voltage (rated): 24VDC, useable on 12-28VDC
- Current: 1.1A
- Power: 26W
- Blade Diameter: 5-5/8"
- Dimensions: 6-3/4 x 5-7/8 x 2"
- Manufactured by PAPST (Made in Germany)

Part Number: 6424/2H

Price: \$14.95 10+ \$12.95

60 x 60 x 20mm 12VDC Brushless Fan



- CFM: 13.06
- Voltage: 12VDC
- Current: .11A
- Noise: 24dba
- Dimensions: 60 x 60 x 20 mm
- Manufactured by Delta Electronics

Part Number: AUB0612LD

Price: \$1.90 10+ \$1.59 100+ \$0.99

12VDC 52CFM Fan



- CFM: 52
- Voltage: 12VDC
- Current: .3A
- Blade Diameter: 3-3/8"
- 6" leads
- Dimensions: 3-5/8 x 3-5/8 x 1.0"
- Manufactured by AVC

Part Number: C9025S12H

Price: \$2.99 10+ \$2.49 100+ \$1.99

12VDC, 6.8 RPM Gear Motor



- Rated at 6.8 RPM @12VDC
- 5mm (3/16") dia x 10mm (3/8") flatted steel shaft with bronze bearings
- Dimensions: L: 2-11/16", (body) Dia: 1-1/4"
- Manufactured by Igarashi Motors

Part Number: 2732-0300

Price: \$12.95 10+ \$9.95

Slim SPST, 10A High Isolation Structure Relay



- Nominal voltage: 12VDC
- Nominal current: 44mA
- Coil resistance: 273 Ohms \pm 10%
- Max voltage: 15.6VDC
- Manufactured by Hankuk

Part Number: HR-CR7DC12

Price: \$0.49

See Our Web Site For Additional Specifications!

mCU Controlled True RMS High Accuracy DMM

The CSI2205D Micro Control Unit auto-ranging DMM is **UL Approved** and designed for measuring resistance, capacitance, DC & True RMS AC voltage, DC & True RMS AC current, frequency, duty cycle and temperature, along with the ability to test diodes, transistors and continuity. A special feature included is the Auto Test Lead Input Indication Technology. This will ensure that whenever you switch functions on the DMM, the proper positive port LED will light indicating where to plug the red test lead into so that no mistakes can be made by the user. It even goes so far as to give a warning tone if you do plug the lead into the incorrect jack! A very helpful feature for the novice and even for the experienced user who is using the meter in less than ideal lighting conditions. Overall, we find this to be a meter that compares very favorably with much higher priced competitors on the market today!

Details at Web Site

➤ Test Equipment ➤ Digital Multimeters

Item # CSI2205D

HOT Item!



Only \$59.00

Stepper Motors

Part #:	Motor Frame Size:	Holding Torque:	Price:
42BYGH404	NEMA 17	3.4kg.cm/47oz.in	\$17.95
57BYGH207	NEMA 23	8kg.cm/111oz.in	\$24.95
57BYGH303	NEMA 23	15kg.cm/208oz.in	\$29.95
57BYGH405	NEMA 23	20kg.cm/277oz.in	\$34.95
85BYGH350B-03	NEMA 34	48kg.in/665oz.in	\$79.95
85BYGH350C-03	NEMA 34	63kg.cm/874oz.in	\$119.95



Stepper Motor Controllers: 2 Phase Microstepping Stepper Motor Driver (Bi-polar & Unipolar Motors)

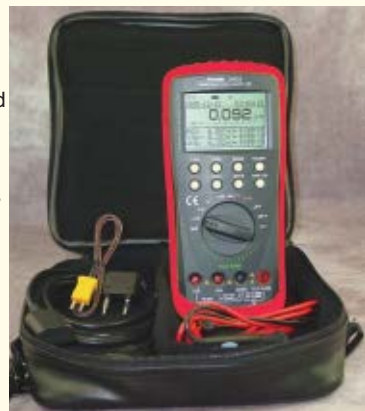


Part #:	Dimensions:	MicroStep:	Price:
XCW220	100mm x 61mm x 19mm	1(200), 1/2(400), 1/4(800), 1/8(1600)	\$39.95
CW220	99mm x 65mm x 30mm	1/2(400), 1/8(1600)	\$49.95
CW230	115mm x 72mm x 32mm	1(200), 1/2(400), 1/4(800), 1/8(1600), 1/16(3200), 1/32(6400), 1/64(12800)	\$59.95
CW250	140mm x 94mm x 45mm	1(200), 1/2(400), 1/8(1600)	\$69.95
CW860	147mm x 97mm x 30mm	1(200), 1/2(400), 1/4(800), 1/8(1600), 1/16(3200), 1/32(6400), 1/64(12800), 128(25600), 1/5(1000), 1/10(2000), 1/25(5000), 1/50(10000), 1/125(25000), 1/250(50000)	\$119.95

100,000 Count Programmable Data Logging DMM

A power house DMM with 100,000 count accuracy and a built-in data logger that will help you find intermittent

problems and monitor equipment while you are busy working on other jobs. The D620 can record and store in it's own internal memory up to 37,300 time stamped data values in all functions by simply pressing a button. Finally, a DMM that provides the user with features and performance at a fraction of the cost of a similar FLUKE DMM.



- 0.05% of basic accuracy, 100,000 count of high resolution
- Data Logger Memory: 37,300 Points
- RS-232C interface
- True RMS measurements for AC
- Auto Calibration

Only \$169.00

Item# PROTEK D620

Details at Web Site

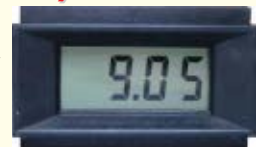
➤ Test Equipment ➤ Digital Multimeters

3-1/2 Digit LCD Panel Meter (enhanced version)

The PM-128E is an enhanced version of our best selling PM-128A. The E version can be set to work with either a 5VDC or 9VDC power source, will perform with either a common ground or an isolated ground, and is supplied with easy to use jumper points so the end user can easily set the measurement range required.

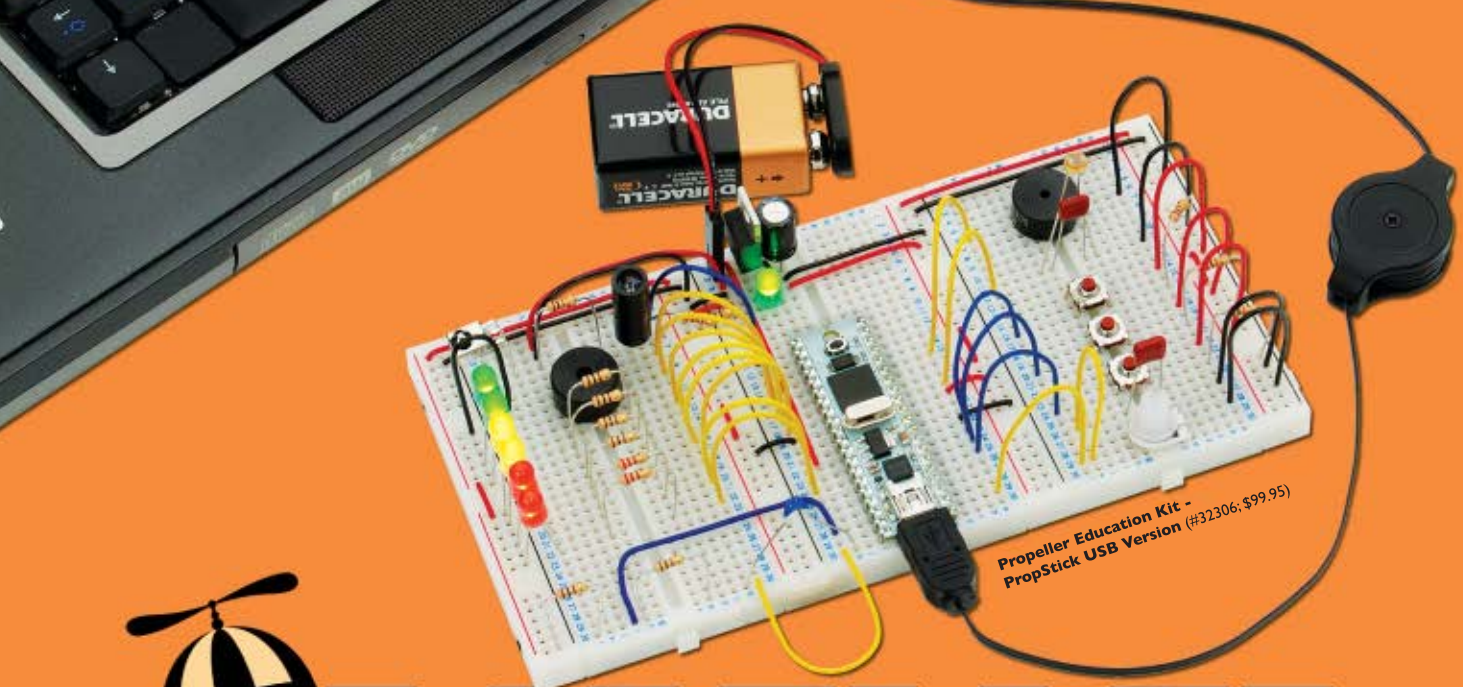
Details at Web Site

➤ Panel Meters ➤ Digital LCD Display



\$12.25 Quantity Price Breaks at website!

Item# PM-128E



Propeller Education Kit -
PropStick USB Version (#32306; \$99.95)



PROPELLER UNIVERSITY

Unsure of how to get started with the Propeller microcontroller? Our education team has developed an ongoing series of Propeller Education Kit Lessons and Labs (available free online) which work seamlessly with our Propeller Education Kits.

Both versions of the Propeller Education Kit include everything you'll need to get started and complete the Propeller Education Kit Lab series, including components, breadboards, connectors, and of course, the Propeller microcontroller.

The **Propeller Education Kit PropStick USB Version** (#32306; \$99.95) features the PropStick USB, a module that you can plug into a breadboard and get up and running with minimal time and wiring. The **Propeller Education Kit 40-pin DIP Version** (#32305; \$79.95) features the breadboard-friendly DIP versions of the chips built into the PropStick USB module. Students can plug in and connect all the parts to build their own system right on the breadboard. Circuit mistakes aren't so scary with the 40 pin DIP version because each part is inexpensive and easy to replace. Start today! ***It's easier to get started with the Propeller than you can imagine.***



Order **Propeller Education Kits** at www.parallax.com or call our Sales Department toll-free at 888-512-1024 (Monday-Friday, 7 a.m. - 5 p.m., PDT).

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